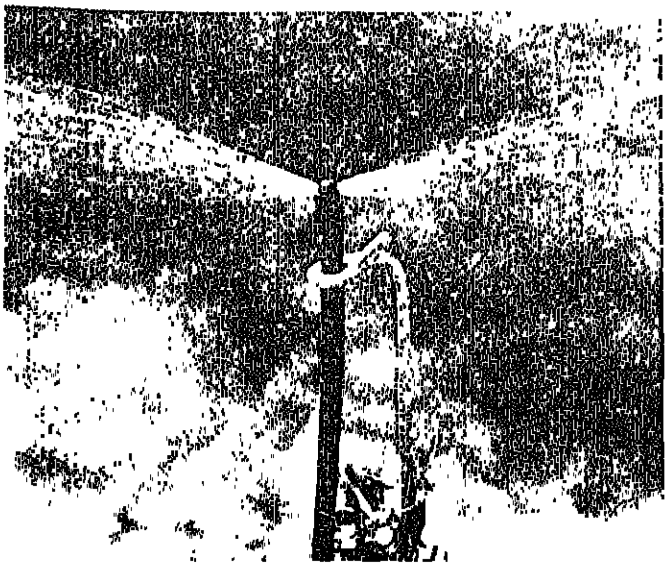
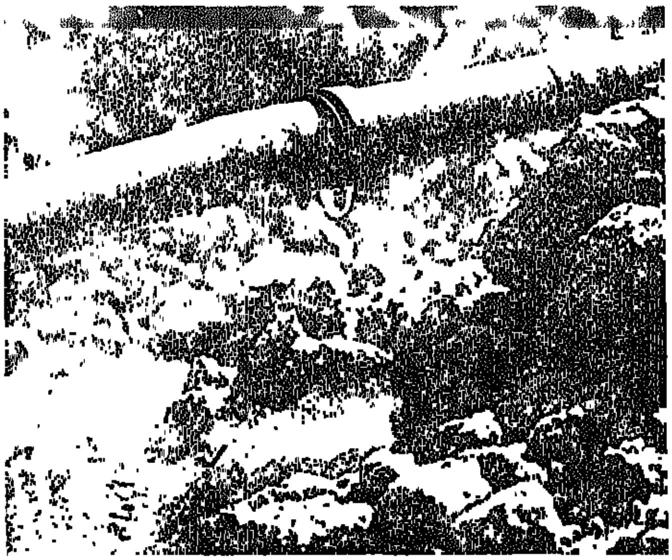
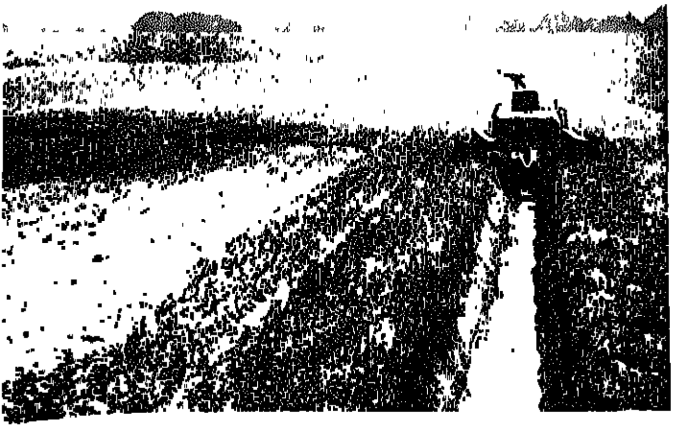
South Carolina Irrigation Guide







USDA - SOIL CONSERVATION SERVICE
SOUTH CAROLINA IRRIGATION GUIDE

Foreword

This guide contains information for planning, design, and operation of irrigation systems consistent with sound irrigation principles. The guide is designed to supplement, but not to supercede national or state standards, specifications, or other requirements of the USDA Soil Conservation Service (SCS). It was prepared in South Carolina by SCS under the leadership of W. Burton Wells, State Conservation Engineer, with assistance from other Government and University personnel using South Carolina data and applicable material obtained from out-of-state, SCS Irrigation Guides. It is anticipated that this guide will be used primarily by SCS and Extension personnel, private engineers, and others who are qualified to provide irrigation planning and design assistance to landowners and operators.

Grateful acknowledgement is given to the American Association for Vocational Instructional Materials (AAVIM) for allowing the use of several drawings from the book, "Planning for an Irrigation System." Appreciation is also expressed to staff members of Clemson University Departments of Agricultural Engineering and Agronomy, the South Carolina Cooperative Extension Service, Agricultural Research Service, U. S. Geological Survey, S. C. Water Resources Commission, and the SCS South National Technical Center who assisted in reviewing the irrigation guide and provided many helpful comments and suggestions for its improvement.

Particular appreciation is expressed to the following individuals, who in addition to reviewing certain chapters, coordinated the review of other chapters among personnel in their agencies: Mr. Charles Privette, Extension Agricultural Engineer, Clemson University; Mr. Gary Speiran, Hydrologist, U.S. Geological Survey, Columbia, South Carolina; and Dr. Carl Camp, Agricultural Engineer, Coastal Plains Soil & Water Conservation Research Center, Florence, South Carolina. The primary coordinator of the irrigation guide was SCS Assistant State Conservation Engineer Remer Dekle.

This guide is a complete revision of the South Carolina Sprinkler Irrigation Guide originally prepared in the 1950's and revised in the sixties and seventies.

January 1987

SOUTH CAROLINA IRRIGATION GUIDE

CONTENTS

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 1. INTRODUCTION

Contents

Figures

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 1. INTRODUCTION

PURPOSE AND OBJECTIVE

This irrigation guide is for the entire state of South Carolina. The guide has been prepared by the Soil Conservation Service with assistance from other Federal and State Agencies for use by trained personnel in planning and designing irrigation systems and use in irrigation water management. The basic data will assure the irrigator that the irrigation system will be capable of supplying the quality and quantity of water needed by plants for optimum production and that with proper seasonal adjustments, irrigation water can be applied efficiently. Recommendations included in this guide are for the most common types of irrigation systems now used in the state.

Some basic data for economic evaluation are included. However, it must be kept in mind that the economics of irrigation are usually an individual field or farm determination in which various other factors may enter.

Many principles of conservation irrigation are basic for other aspects of planning such as drainage and erosion control. The guide should form a sound basis for collecting and evaluating needed additional information.

RAINFALL IN SOUTH CAROLINA

AVERAGE RAINFALL

The average annual rainfall of the Southeast River Basins is about 50 inches. The United States average is about 30 inches. Figure 1-1 shows the average annual rainfall over South Carolina.

Based on 90 years of record, the mean is about 48 inches with extremes ranging from 33 inches in 1954 to 72 inches in 1964.

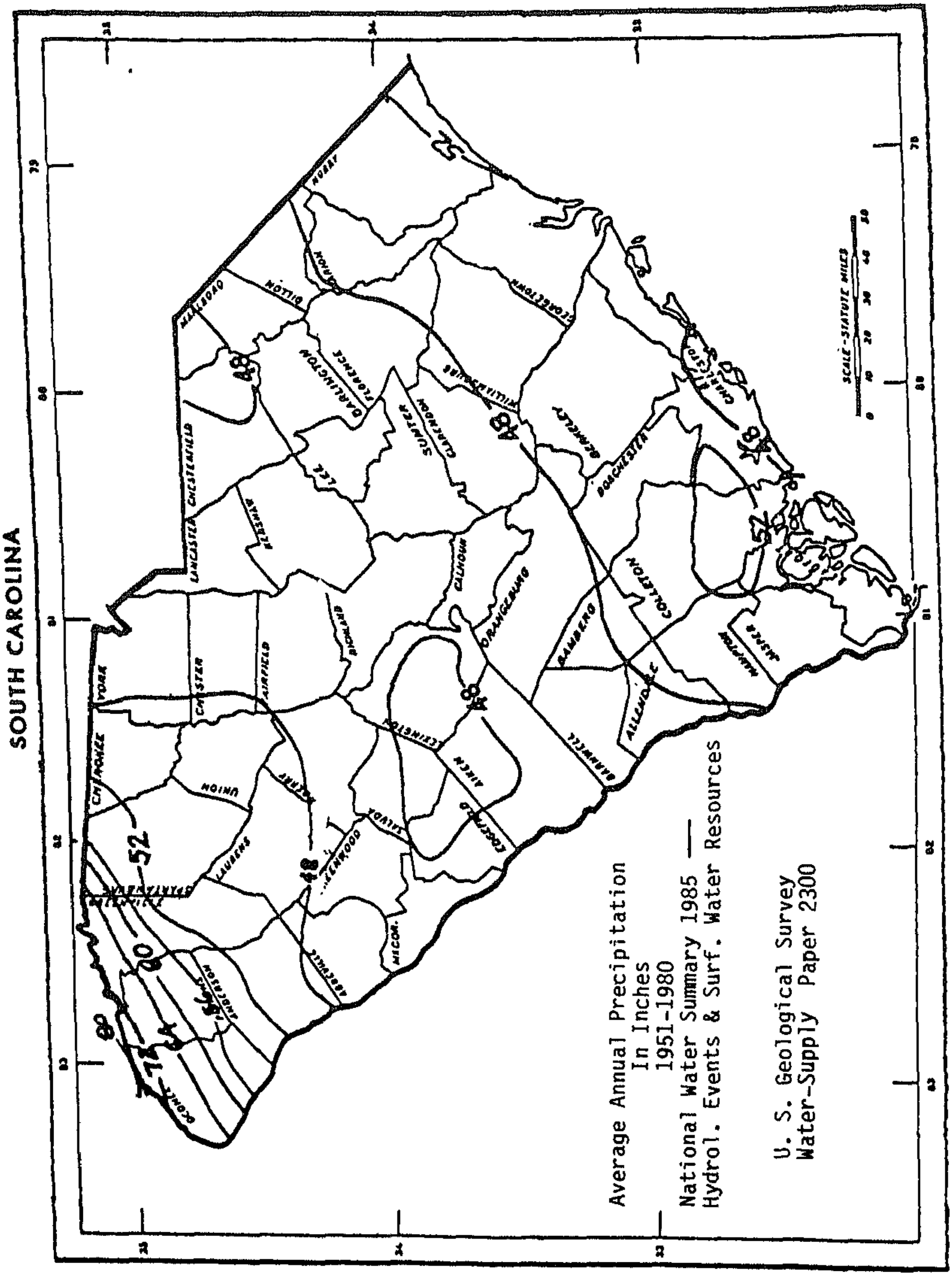

SOUTH CAROLINA
Average Annual Precipitation
In Inches
1951-1980
National Water Summary 1985 —
Hydrol. Events & Surf. Water Resources
U. S. Geological Survey
Water-Supply Paper 2300

Figure 1-1

SEASONAL DISTRIBUTION OF RAINFALL

Figure 1-2 shows the normal seasonal distribution of monthly rainfall for three climatic zones in South Carolina for the period 1951-1980 (see ch. 4 for zone boundaries).

Season	Normal Precipitation (Inches) Zone 1	Zone 2	Zone 3
Winter 1/	12.87	11.07	10.47
Spring 2/	13.93	11.98	11.42
Summer 3/	12.77	15.24	17.04
Fall 4/	10.21	9.02	9.88
Annual	49.78	47.31	48.81

1/ December, January, February
2/ March, April, May
3/ June, July, August
4/ September, October, November

Figure 1-2

In general, the rainfall is fairly well distributed throughout an average year, with most of the rain occurring during the growing season. Variations in seasonal and especially monthly rainfall from year to year are often significant. For example, the standard deviation of the normal monthly rainfall varies from about 40 to 55 percent. This means that about 32 percent of monthly rainfall measurements would vary more than 40 to 55 percent from the normal.

The summer peak, which is more prominent in the southeasterr
state, is a product of thunderstorms which produce a large p
summer rainfall. The climatic effect of hurricane rainfall
insignificant because hurricanes occur infrequently at any l
their aggregate rainfall is small compared with the scattere
frequent, thunderstorm rainfall.

YEAR-TO-YEAR VARIABILITY OF RAINFALL

The variation in total annual rainfall from year to year car
Extremes of 50 percent more an 50 percent less than average
most records. Significantly, the annual rainfall is rarely
United States average of 30 inches.

TEMPERATURE

AVERAGE AND SEASONAL DISTRIBUTION

Figure 1-3 shows the average daily temperature in degrees Fahrenheit for 3 climatic zones in South Carolina (see chapter 4 for zone boundaries). In general, the average daily temperature at the height of summer is slightly below 80°. July temperatures averaging about 75° are typical of most of the United States.

	Average Daily Temperatures (°F)		
Season	Zone 1	Zone 2	Zone 3
Winter 1/	44.0	46.5	47.6
Spring 2/	61.1	63.4	63.6
Summer 3/	77.7	79.1	79.0
Fall 4/	62.3	64.2	65.0

1/ December, January, February
2/ March, April, May
3/ June, July, August
4/ September, October, November

Figure 1-3

In January, the average daily temperature in South Carolina is about 40°F in the mountains, 45° over much of the Piedmont province, and 50° over much of the Coastal Plain.

DAILY RANGE OF TEMPERATURE

The average daily temperature range is about 20°F, with the minimum usually at sunrise and the maximum usually early in the afternoon. Exceptions to this regime occur, of course, with a frontal passage and a change in air mass; strong wind and mixing; and dense clouds. With unusually long duration of cloudiness or with dense coulds, the daily temperature range may be less than 10°; and with clear skies, dry air, and light wind the range frequently exceeds 30°.

On an average January day the temperature rises to more than 50°F in the mountains, the low 60's in the central part of the state, and reaches 70° in the extreme southeast part. the minimum temperature during an average January day is 30° in the mountains, 40° in the central part, and nearly 50° in the extreme southern portion.

In July the average daily maximum temperature is about 90°F over most of South Carolina and somewhat less in the mountains. During a typical July night the temperature falls to about 70° over most of the state. In the mountains, the minimum is about 60°, and the coast is in the low 70's.

GROWING SEASON AND DEGREE DAYS

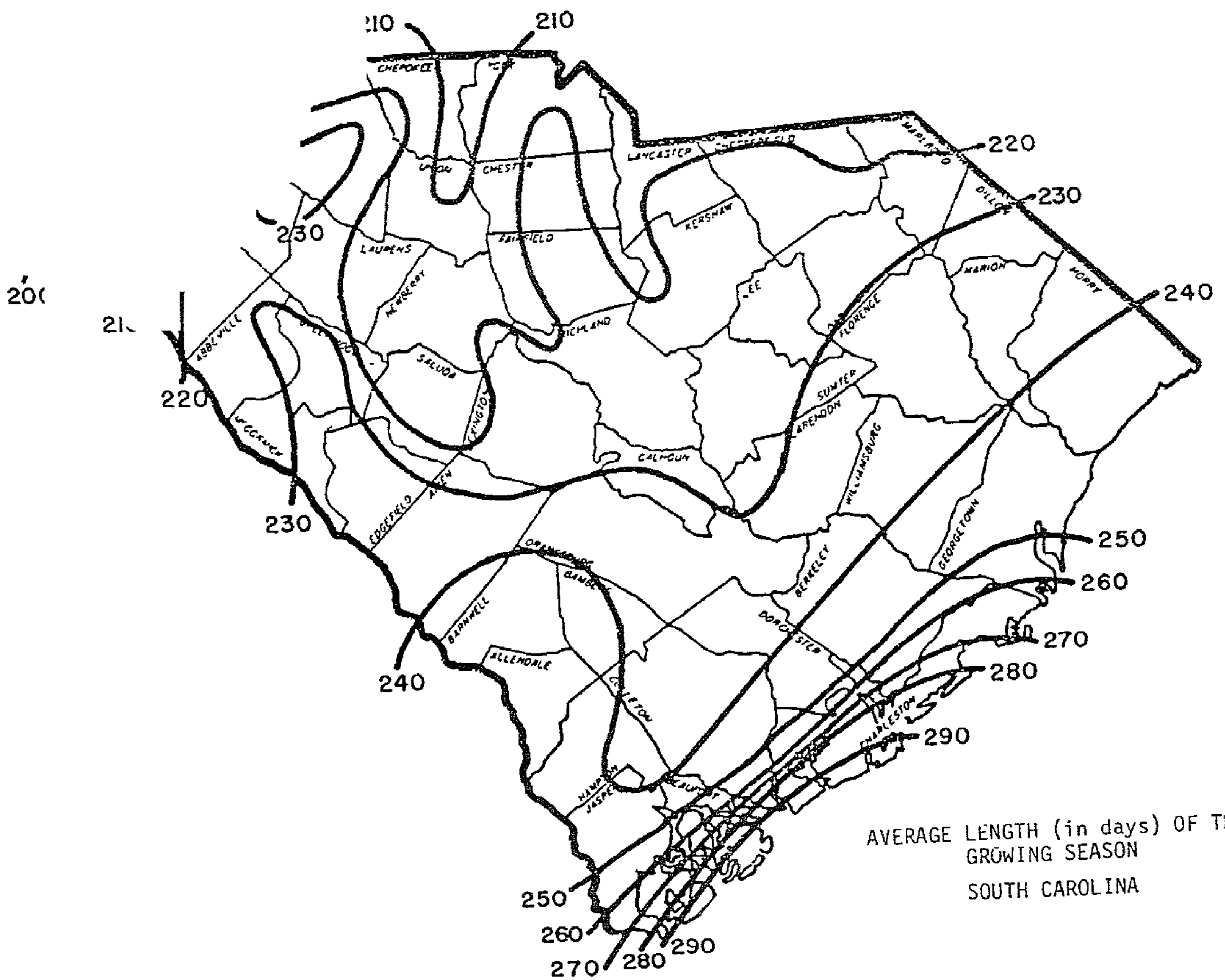
Growing season is defined as the period between the last occurrence in spring and the first occurrence in autumn of temperatures below a given base. This base is different for different plants, some being much hardier than others. Tomatoes are damaged at temperatures below 32°F, wheras peas and cabbage can withstand temperatures as low as 24° for brief periods. Figure 1-4 shows the average frost-free period or length of growing season for sensitive plants. The number of days range from 200 in the mountains to 290 in the extreme southeast, with most of the state having about 230. These values vary, of course, from year to year. In the north, the length of growing season is within about 20 days of the average two-thirds of the years, and in the south it is within about 30 days two-thirds of the years.

Figure 1-5 shows the average date of the last freeze in spring, and Figure 1-6 shows the average date of the first freeze in autumn. Both figures apply to sensitive plants. For hardy plants, the average growing season limits would be about 25 days earlier in spring and about 20 days later in autumn.

WIND

Winds are predominantly southwesterly and northeasterly over most land areas. Average wind speeds are 5 to 10 mph for the state.

Physiographic influences in South Carolina are important. Stations such as Charleston, which are near the open coast, have average wind speeds of 7 to 10 miles per hour; stations, such as Anderson, on ridges or plateaus, have average wind speeds of 8 to 10 miles per hour; and at relatively sheltered valley stations such as Columbia, the winds average 5 to 7 miles per hour.



AVERAGE LENGTH (in days) OF THE GROWING SEASON

SOUTH CAROLINA

... Climatological Data for period 1931-1960

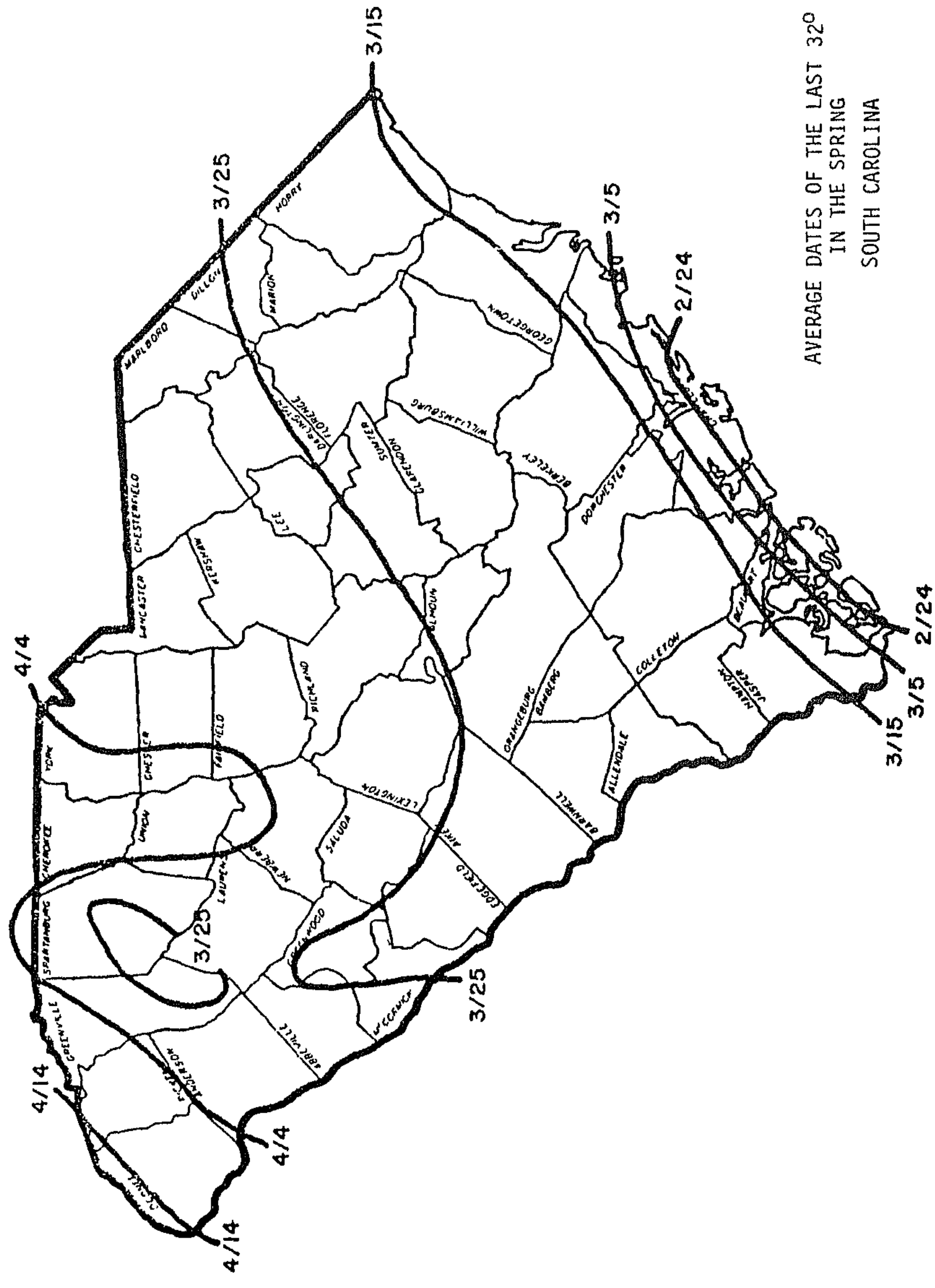

AVERAGE DATES OF THE LAST 32°
IN THE SPRING
SOUTH CAROLINA
3/15
3/25
3/5
2/24
4/4
3/25
3/25
4/14
4/4
4/14
2/24
3/5
3/15

Figure 1-5

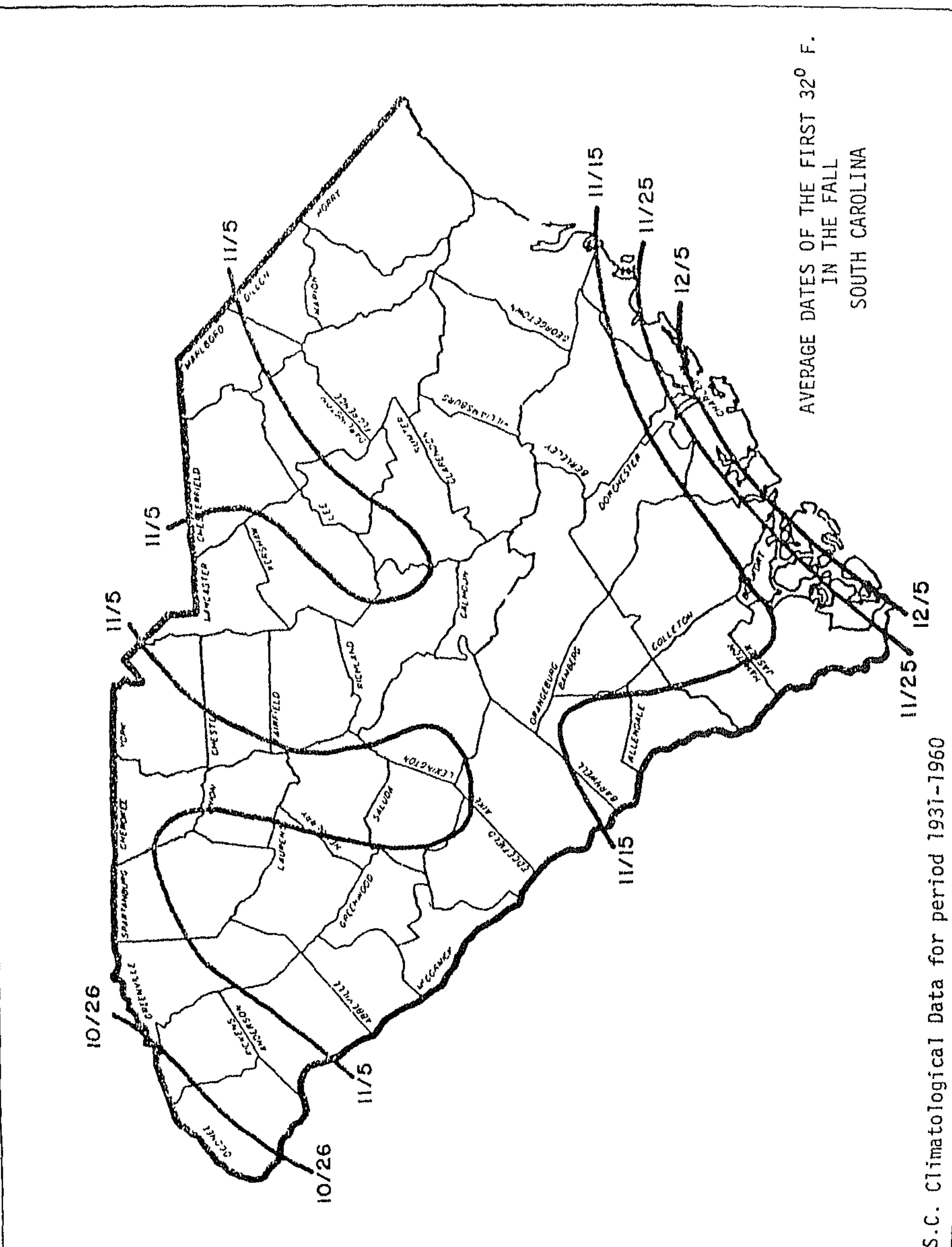

AVERAGE DATES OF THE FIRST 32° F.
IN THE FALL
SOUTH CAROLINA
Source: S.C. Climatological Data for period 1931-1960
10/26
11/5
11/15
11/25
12/5
OCONEE
PICKENS
ANDERSON
GREENVILLE
SPARTANBURG
CHEROKEE
YORK
CHESTER
UNION
LAURENS
GREENWOOD
ABBEVILLE
McCORMICK
EDGEFIELD
SALUDA
AIKEN
LEXINGTON
FAIRFIELD
RICHLAND
LANCASTER
KERSHAW
CHESTERFIELD
MARLBORO
DILLON
MARION
HORRY
LEE
SUMTER
CLARENDON
CALHOUN
ORANGEBURG
BAMBERG
BARNWELL
ALLENDALE
COLLETON
DORCHESTER
BERKELEY
WILLIAMSBURG
GEORGETOWN

Figure 1-6

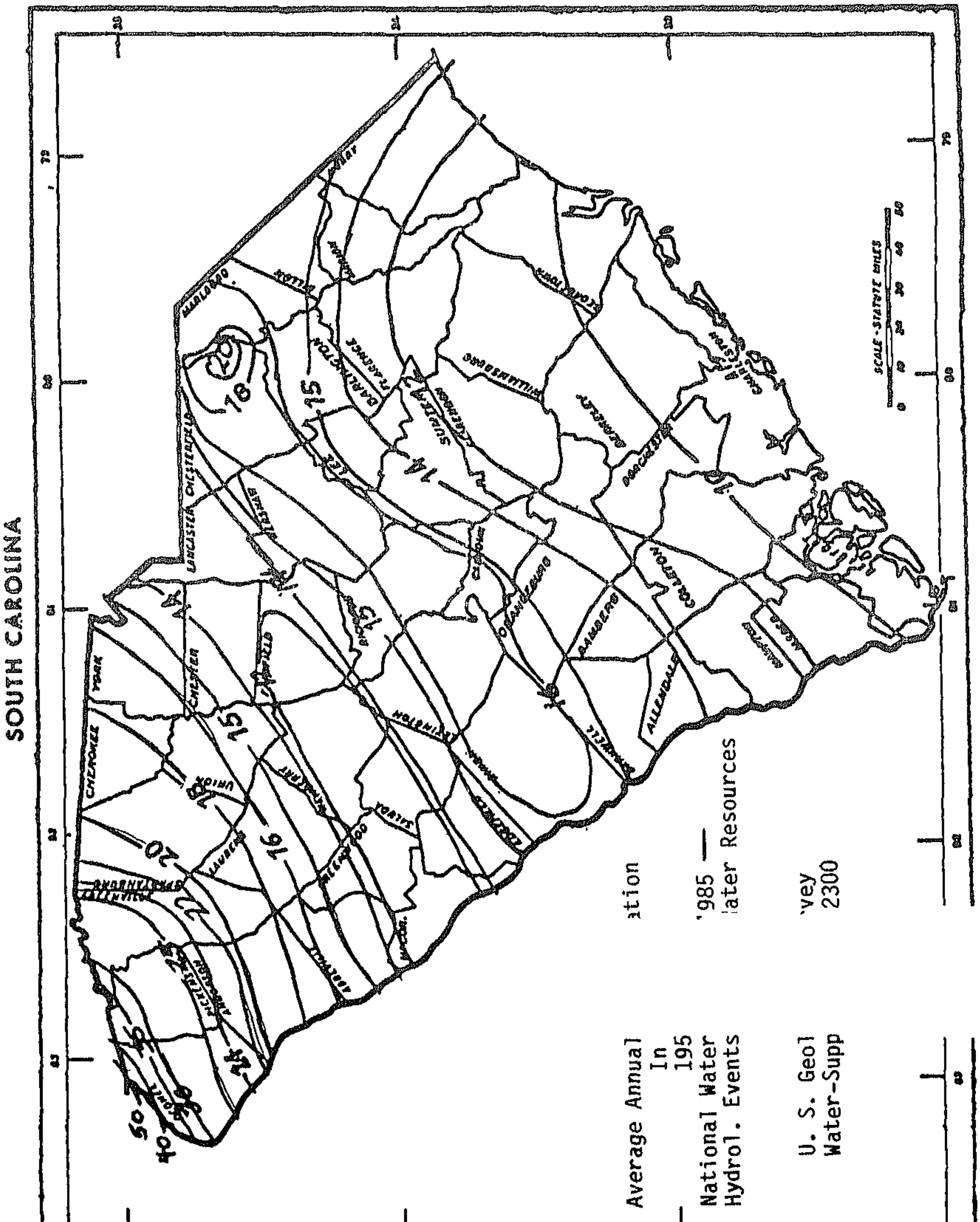

SOUTH CAROLINA
Average Annual ation
In 195 '985 —
National Water ater Resources
Hydrol. Events
U. S. Geol vey
Water-Supp 2300

Figure 1-7

SURFACE WATER

AVERAGE STREAMFLOW

The average annual streamflow in South Carolina represents about 22 inches average depth over the State (U.S. Geological Survey, 1985), compared to the United States average of about 8 inches. The range of annual streamflow is from about 10 inches in the lower Coastal Plain and lower Piedmont to about 45 inches in the Blue Ridge (mountains).

SEASONAL DISTRIBUTION OF STREAMFLOW

Regardless of variations in the seasonal rainfall pattern, the average streamflow, except in certain coastal areas, is high in early spring and recedes to a low in late autumn. This average seasonal regime is typical even of most small streams in the rural areas. The summer rainfall peak does not ordinarily produce a summer runoff peak because summer showers usually fall on relatively dry soil and because much moisture is transpired by vegetation or evaporates directly to the air in summer, thus leaving relatively little contribution to runoff.

LOW FLOWS

Streams in the lower Coastal Plain and lower Piedmont normally have poorly-sustained base flows and some streams periodically go dry during late summer and fall. This is in contrast to the Blue Ridge province and upper Coastal Plain (figure 1-8, B) where base flows are well-sustained.

More information on low flows of streams in South Carolina may be obtained from the following publications of the South Carolina Water Resources Commission by Bloxham (1976, 1979, 1981).

Bloxham, W. M. 1979. Low-Flow Frequency and Flow Duration of South Carolina Streams. South Carolina Water Resources Commission, Report No. 11. 90 pp.

Bloxham, W. M. 1976. Low-Flow Characteristics of Streams in the Inner Coastal Plain of South Carolina. South Carolina Water Resources Commission, Report No. 5. 28 pp.

Bloxham, W. M. 1981. Low-Flow Characteristics of Ungaged Streams in the Piedmont and Lower Coastal Plain of South Carolina. South Carolina Water Resources Commission, Report No. 14. 48 pp.

WITHDRAWALS

The average surface water discharge from South Carolina is about 33 billion gallons per day (U.S. Geological Survey, 1985). Between 1970 and 1980, total offstream water use in South Carolina nearly doubled to 5,780 million gallons per day (Mgal/d). This amount is projected to increase to about 8,550 Mgal/d by the year 2020 (South Carolina Water Resources Commission, 1983).

WATER QUALITY

General

The quality of South Carolina's surface water is generally excellent and suitable for most uses. The water is soft and has a low buffering capacity. There are no known significant quality problems concerning irrigation of surface water.

Temperature

The natural temperature in large streams is near the average monthly air temperature. In smaller streams, day-to-day fluctuations in water temperature are greater than for the larger streams and in the smallest streams, hour-to-hour variations are evident with the daily range of temperature being nearly as great as for the nearby air.

Dissolved Solids and Acidity

The range of dissolved solids for surface water in South Carolina is from less than 15 to more than 100 mg/L with values generally ranging from 20 to 80 mg/L. The ph of surface water generally will be in the range from about 5.0 to 7.5 with alkalinity ranging from about 1 to 40 mg/L.

GROUND WATER

WATER-BEARING FORMATIONS (Aquifers)

The areal distribution of the principal aquifers in South Carolina are shown in figure 1-8. The Piedmont and Blue Ridge aquifers occur in alluvial deposits of sand and gravel; in weathered saprolite; and in joints, fractures and fault zones of cystalline bedrock.

The Coastal Plain aquifers occur in a wedge shaped area consisting of sand, clay and limestone sediments overlaying metamorphic and sedimentary rocks. The wedge, thickening from the Fall Line toward the coastline, can be divided into aquifers and confining units based on relative permeabilites, and other factors (figure 1-8, C) Water generally moves laterally within each aquifer with confining units inhibiting but not preventing vertical movement of water between aquifers. (Ancott and Speiran, 1984)

Ancott and Speiran, 1984. Ground Water Flow in the Coastal Plain Aquifers of South Carolina, U. S. Geological Survey.

WATER AVAILABILITY

In general, the Blue Ridge and Piedmont Provinces have limited ground water supplies because of their geology. The underlying igneous and metamorphic rock (overlain by a weathered surface) is dense and crystalline and water is available only in the thin soil mantle and fracture zones of the rock itself.

Within the Coastal Plain, thick sedimentary aquifers provide substantially greater supplies of generally good quality water. Ground water can be obtained nearly everywhere by drilling a well and pumping.

WELL DEPTHS

Most water is stored in the top several hundred feet in the Piedmont and Blue Ridge Provinces, thus well depths usually stay within this range. Wells in the Coastal Plains often produce adequate yields at depths less than 500 feet (ft) but it is not rare for depth to be 1000 ft or greater.

WELL YIELD AND WATER LEVELS

In the Piedmont and Blue Ridge, typical wells yield 10 to 30 gallons per minute (gpm) with water levels generally less than 100 ft but sometimes exceeding 200 ft from the ground surface. Water levels in most deep Coastal Plain wells (several hundred ft.) prior to development usually are within 50 ft. beneath the

surface and sometimes above land surface in the lower Coastal Plain due to artesian conditions. In upland areas of the upper Coastal Plain, water levels prior to development may be deeper than 200 feet. (personal communication, Gary Speiran, 1986)

Most large capacity wells in the Coastal Plain are screened in the Black Creek or the Middendorf (Tuscaloosa) Aquifer. Potential yields range from several hundred to greater than 2000 gpm. Little decline in water levels is being experienced except in heavily pumped areas of Florence, Myrtle Beach, and Savannah. Declines in the Florence area are reported to be greater than 100 ft. since 1930 for selected wells. (Ancott & Speiran, 1985a, 1985b)

After development, water levels in wells screened in the Black Creek and Middendorf aquifer are commonly in the range from 50 to more than 250 ft. from the soil surface at the pumping well. (personal communication, Gary Speiran, 1986) The actual water level at any particular well during pumping is dependent on many factors including static water level prior to pumping, permeability of in-place materials and the gravel pack or filter at the screened sections, the well screen itself, transmissibility of the aquifer, and the discharge of the well.

Screens or perforated casings are utilized in unconsolidated sand and gravel aquifers to allow water to enter the well and to stabilize the aquifer material. Consolidated rock aquifers often may be completed without perforated casing or screen. Due to the cost of screens, usually only the higher yielding zones are screened, resulting in some wells being multi-screened. Zones of poor quality water should not be screened if ample quantity of good quality water is available at different depths.

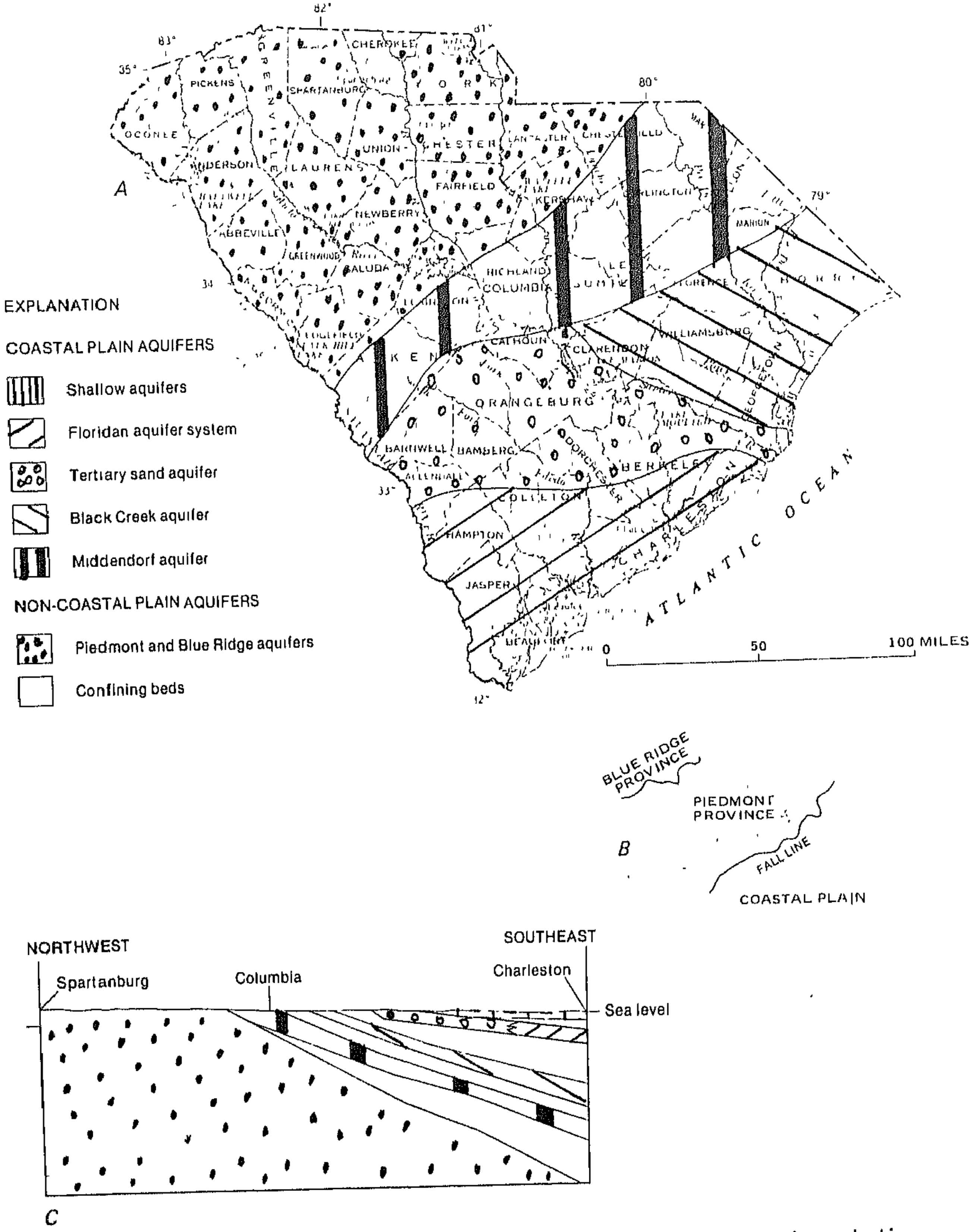


Figure 1-8. Principal aquifers in South Carolina. A, Delineations indicating the most widely used aquifers. B, Physiographic diagram and divisions. C, Generalized cross section. (See table 2 of the National Water Summary - South Carolina for a more detailed description of the aquifers. Sources: A, C, Compiled by W.R. Aucott from U.S. Geological Survey files. B, Fenneman, 1938; Raisz, 1954.)

For more information, see South Carolina Technical Note Engineering 2 (Geology) on file in SCS county offices, S.C. Water Resources Publications, or U.S. Geological Survey Reports as referenced.

Aucott and Speiran. 1984. Water Level Measurements for the Coastal Plain aquifers of South Carolina prior to development. U. S. Geological Survey Open-File Report 84-803.

Aucott, W. R. and G. K. Speiran. 1984a. Potentiometric surfaces of the Coastal Plain aquifers of South Carolina, prior to development. U. S. Geological Survey Water-Resources Investigations Report 84-4208.5 sheets.

Aucott, W. R. and G. K. Speiran. 1984b. Potentiometric surfaces for November 1982 and declines in the potentiometric surfaces between the period prior to development and November 1982 for the Coastal Plain aquifers of South Carolina. U. S. Geological Survey Water-Resources Investigations Report 84-4215.7 sheets.

WITHDRAWALS

The 1980 withdrawal of ground water in South Carolina was slightly less than 210 mgal/d (Lonon & Others, 1983). This is equivalent to about two-sevenths inch average depth per year over the southeastern half of the state. A question to be considered is what rate of withdrawal could be sustained. As indicated by water level declines in areas where ground water pumpage is greatest (Myrtle Beach, Florence, Sumter, and Savannah, withdrawals may be approaching maximum sustainable yields locally. In other areas of the Coastal Plain, ground water is relatively undeveloped thus significant increases in withdrawals over present rates should be sustainable in most situations.

Ground-water withdrawals for irrigation are seasonal, usually are spaced widely, and are located mostly in the upper part of the Coastal Plain where aquifer yields are large. Because

WATER QUALITY

General

Ground water quality as related to irrigation is generally good to excellent in South Carolina. At points along the coast, salt-water intrusion is a problem; and inland there are scattered places where salinity or sulfur limit use. Probably the most widespread problem concerns acidity (alkalinity) and dissolved solids and their effect upon metal parts of irrigation systems. In the Middendorf aquifer along the coast, concentrations of boron of as little as 8 mg/L may cause problems with certain irrigation uses.

Temperature

In general, temperature of ground water is about the same as mean annual air temperature at the water table and increases to more than 100° F at depths greater than 2500 feet. Temperature of water from very shallow wells or from very small springs varies seasonably but temperature of water from deeper aquifers changes very little. Temperature of shallow ground water ranges from about 64 to 69° F in the Coastal Plain and slightly cooler north of the Fall Line to below 60° F in the mountains (Personal Communication, G. Patterson, USGS, Columbia, SC)

Dissolved Solids and Acidity

The ph and alkalinity increases going from the West toward the coast within the range from about 4.0 to 9.0 (ph) with alkalinity less than 1 to greater than 1,000 mg/L. Values of ph are generally between 6.0 and 8.6. (personal communication-Glenn Patterson, USGS, Columbia, SC) At the lower end of the pH range, (acid) damage may occur to well casings, screens, pumps, and the metal parts of the irrigation system. Both acidity and low total dissolved solids, which are known causes of corrosion, are recognized problems in several center pivot systems in Lee and Sumter Counties. Some steel pipes have been severely corroded and have failed after only two to five years use. Results of chemical testing, provided by the Water Resources Commission to irrigators, indicate the probable cause of deterioration of pipes in this area to be a combination of these two problems (acidity and low total dissolved solids). However, there may be some other contributing source not yet investigated.

At present, one recommended action for existing steel pipe systems is to inject lime containing adequate calcium carbonate to neutralize the acid and provide a substance that the water can dissolve instead of dissolving the pipes. The lime is normally injected on the discharge side of the pump. This slows down the attack and depending on the condition of the pipe, it may add many years of life to the system

(personal communication, L. Lagmon, Chemist, SC Water Resources Commission, Columbia, SC). The screen should be of fiberglass, high quality stainless steel, or other material resistant to attack.

The water source for the known problem sites is primarily the Tuscaloosa (Middendorf) aquifer. The suspect area is a strip along the fall line including the upper Coastal Plains from Augusta, Georgia, through Chesterfield, South Carolina. Future ground-water investigations to be conducted by the Water Resources Commission will provide additional data to better define the area and refine treatment procedures.

It is recommended that irrigators have their water supply analyzed to determine the water quality, whether surface or subsurface source is being used.

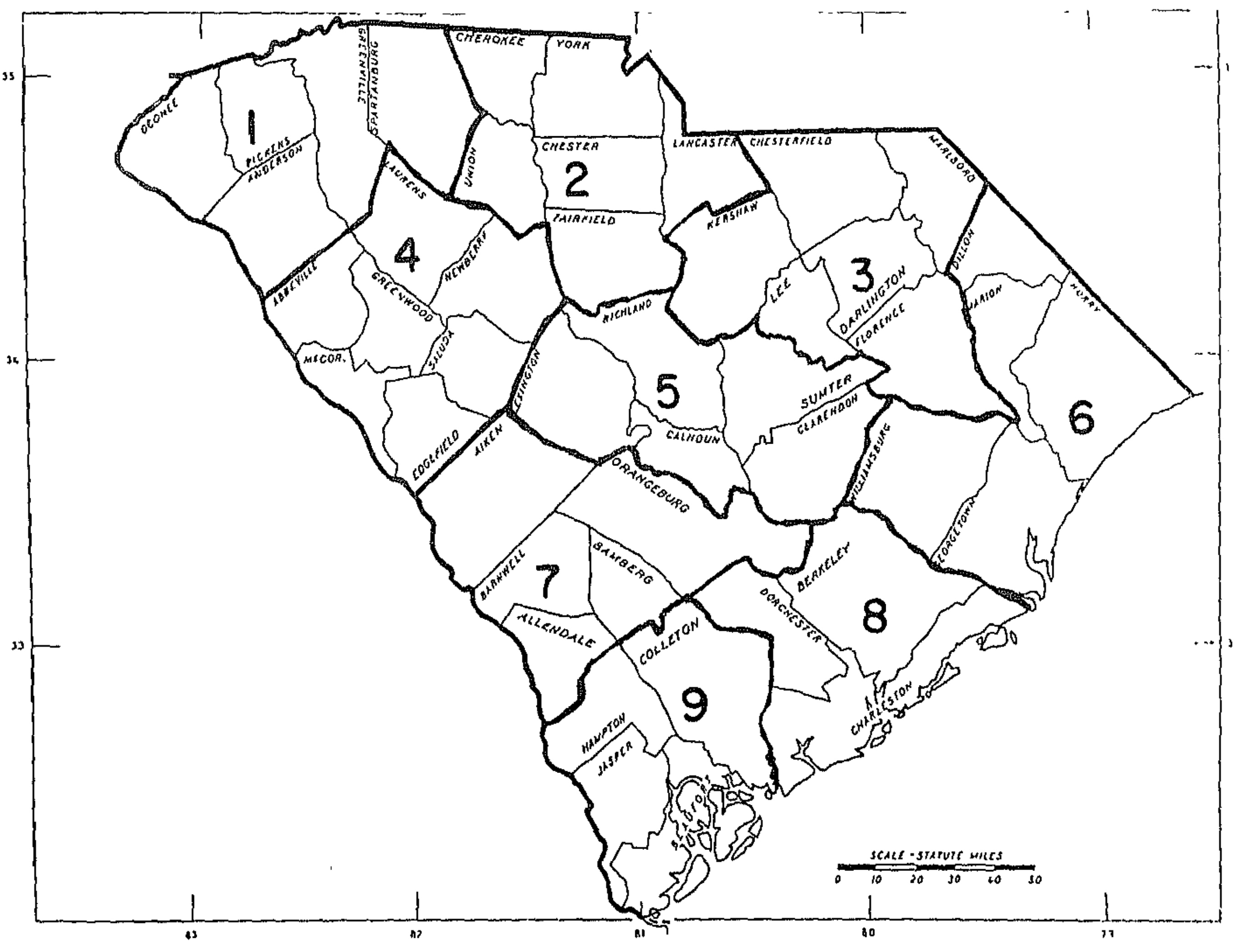
For new systems, a water quality analysis should be made at the test well stage. It is advisable to use PVC or other approved pipe when possible rather than steel pipe for sites where this problem is identified or is likely to develop. Otherwise, the owner should be prepared to replace damaged components or treat as needed for protection. The South Carolina Water Resources Commission currently will obtain samples, do the testing and provide recommendations for treatment on a request basis at no charge for agricultural use when the site is located within one of the Commission's study areas. The Geology-Hydrology divisions Ground-Water Project areas map is shown on Figure 1-9.

For specific information about water quality at a particular location, landowners should address inquiries to the following address:

Water Resources Commission
P. O. Box 4440
Columbia, South Carolina 29240
Phone: 758-2514

Figure 1-9. Ground-Water Project Areas - Water Resources Commission

No.	Name	No.	Name
1	Appalachia	6	Waccamaw
2	Catawba	7	Lower Savannah
3	Pee Dee	8	Trident
4	Upper Savannah	9	Low Country
5	Central Midlands		



Technical personnel are encourages to discuss the acidity and dissolved solid problems with irrigators to make them aware of the known potential problem areas and the need to have their water analyzed.

Sand and Minerals

When pumping from ponds, streams, or wells with suspended sand, the pump and irrigation equipment orifices need to be checked regularly for wear. Sand content does not have to be high enough to make the water unclear for it to cause severe wear. A good indication of pump or orifice wear is a reduction in system pressure at the usual operating speed and water level.

The hardness (mineral content) of the water can cause equipment problems due to mineral deposits closing orifices, freezing sprinklers and mineral encrustation in pipes.

Trickle Irrigation Concerns

Trickle irrigation systems with their small emitter openings and more intricate labyrinth-type internal structures are more easily clogged than other types of irrigation. Clogging seems to be less of a problem in those types of emitters through which the water moves at higher velocities.

Particulate matter and bacterial slimes are the usual causes of these clogging problems. Filtration will take care of the particulate matter problem, but with a high particulate matter content cleaning filters can become a problem.

A combination of chlorine and filters will control the bacteria problem. It should be used a preventive rather than a corrective treatment, because it is very difficult to clean out systems once they are clogged. Chlorine should be metered according to need rather than just "dumped" into the system. Chlorine injection should result in a free residual chlorine level of 0.5 to 1.0 ppm at the end of the system. This level should be maintained for a period of 30-45 minutes and should be applied periodically depending on the quality of the water supply.

Surface water may be suitable for trickle irrigation if chlorine is injected at the pump and a sand filter is used to trap the algae and particulate matter before they enter the lines and emitters.

Before installing a trickle irrigation system, the landowner should have tests run for pH, iron, sulfides and dissolved solids and get advice from experts in the field of chlorine treatment. The sulfides and iron stimulate slime growth.

WASTE WATER APPLICATIONS

Waste water includes water that contains waste from municipal waste treatment plains, industrial plants, food processing facilities, dairies, and livestock operations. This waste water will contain various amounts of nutrients, organic material, and possibly heavy metals.

These waste waters can be used for irrigation, but the amount of this waste water that can be applied and the crops to which it can be applied will be determined by its quality. Irrigation with waste water containing heavy metals is very restricted. The fertility balance of the soil should be maintained by supplementing the waste applications with appropriate commercial fertilizers.

Waste water can be very corrosive causing system life to be limited and maintenance increased. Also, consideration should be given to the solids content of waste water. Large orifices are needed to pass the larger solids without clogging. A pump that chops up the solids may be required, depending on orifice and solid sizes.

Water containing human or animal waste should not be applied to crops that are consumed raw by humans.

For more information on irrigating with agricultural waste see Engineering Standards and Specifications Code 633 - Waste Utilization, the Agricultural Waste Management Field Manual, and Animal Waste Utilization on Cropland and Pastureland (USDA Utilization Research Report No. 6).

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 2. SOILS

Contents

Figures

Tables

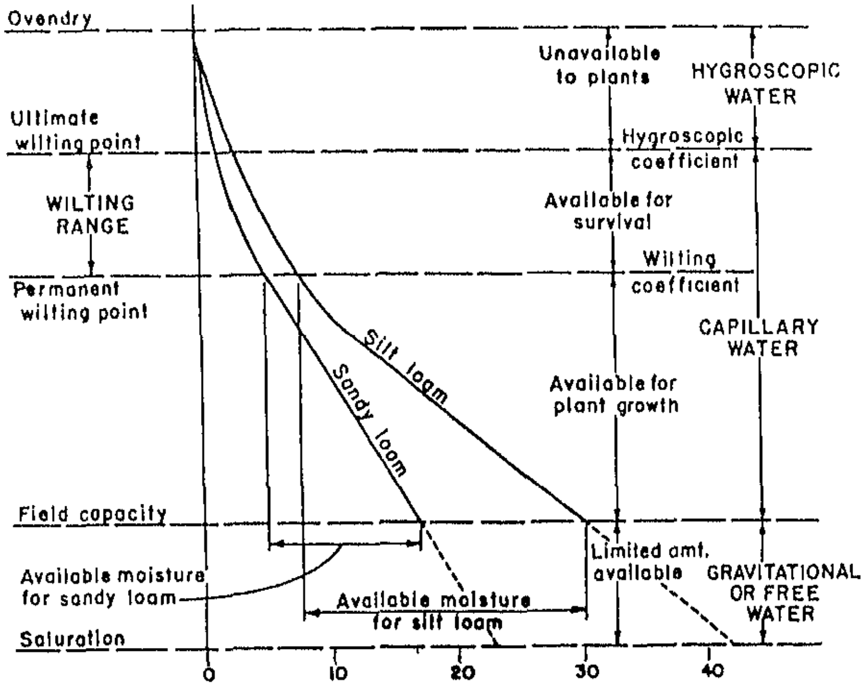
CHAPTER 2. SOILS

GENERAL

A knowledge of soil properties is necessary for the efficient use of water for crop production. Soil survey maps and special request maps are available to all field offices. The different kinds of soils and their distribution are identified on these maps, and important physical and chemical characteristics of each kind of soil are recorded in the SCS technical guides. Some characteristics of soils important to understanding soil-moisture plant relationships are discussed in this guide. They include permeability, intake rate, slope, depth to water table, and texture. All of these help determine the potential available water capacity. Also, organic matter content and bulk density help determine available water capacity.

AVAILABLE WATER CAPACITY AND SOIL MOISTURE TENSION

The available water capacity (AWC) of a soil is a measure of its capacity to make water available for plant growth. The AWC is the amount of water held between field capacity (FC) and the permanent wilting point (WP) as shown in Figure 2-1. AWC is expressed as the water retained between 1/3 bar and 15 bars tension for fine to medium textured soils and between 1/10 bar and 15 bars for moderately coarse to very coarse textured soils.



Soil Moisture Content (Percent by Dry Weight)

Figure 2-1. Soil Moisture Content - Kinds of Water in the Soil

There are a number of methods used to determine when to irrigate. One method is based on soil-moisture tension. The relationship between this concept and AWC is shown by the moisture release curves for three soils, Figure 2-2. In this figure moisture content is expressed as a percentage of AWC rather than as percentage by weight. FC is 100 percent of AWC and the WP (15 bars) is 0 percent of AWC. Tension at any moisture level is different for the three soils. At the 50 percent level, for example, moisture tension for the clay is about 4.3 bars (atmospheres); for the loam, 2.0 bars; and for the sand 0.6 bars. (These values shown for comparison only and do not represent any particular soil.)

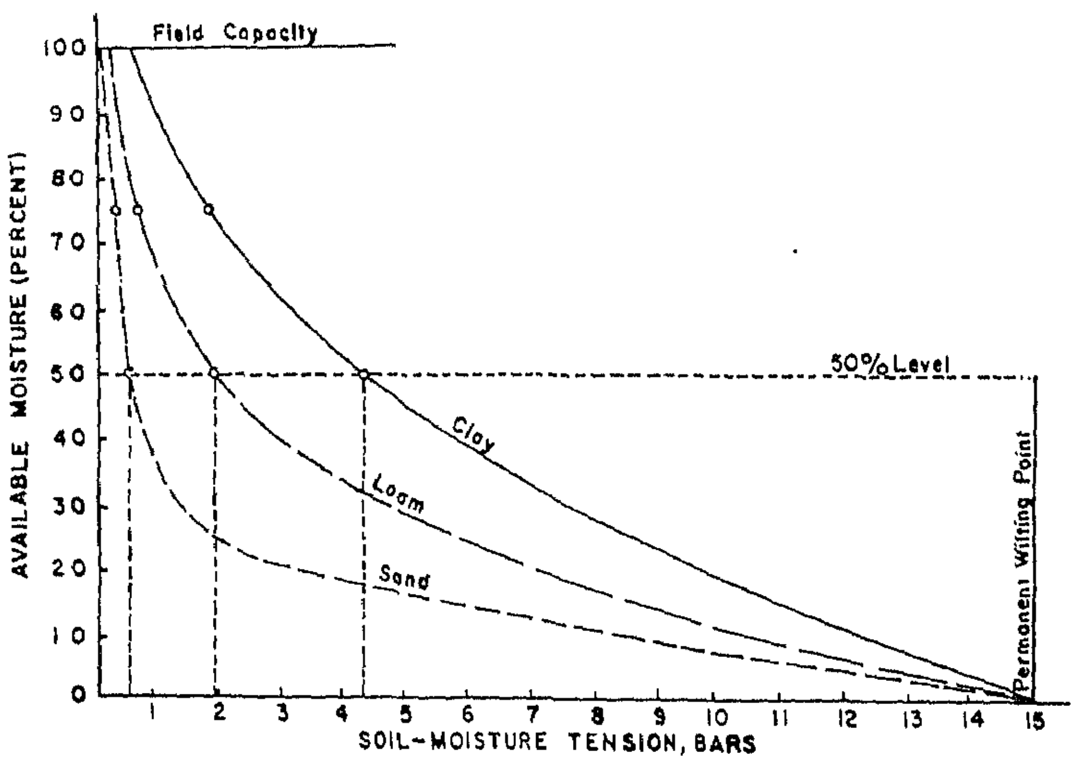


Figure 2-2. Moisture Release Curves for Three Soils

Moisture is more readily available to plants at low soil moisture tension (near field capacity). Since tension values are so different in the three soils shown in Figure 2-2, it is possible that crop response would be different if the soils were irrigated when tension reaches a given value rather than when available moisture is depleted to a given value. See Chapter 3 (Crops) and Chapter 11 (Water Management) for information on when to irrigate.

The SCS Field Office Technical Guide, Section II-B, Soils Descriptions, or either a published soil survey can be used to obtain the AWC for South Carolina soils. For example, the available water capacity of the top 18 inches in a Faceville soil in Aiken County is:

Sandy loam	0"- 6",	0.075 in./in. x 6 in.	= 0.45 in.
Sandy clay	6"-18",	0.150 in./in. x 12 in.	= 1.80 in.
Total AWC for 18 in. depth			= 2.25 in.

Water retention values for various soil water tension levels are shown in Table 2-1 for Southern Piedmont and Coastal Plain soil texture groupings. From this table, water retention for a Faceville soil (coastal plain soil) in Aiken County at the indicated soil moisture tensions may be estimated as follows:

Depth	Texture	.10 bar tension	0.5 bar tension	Difference
0- 6"	Sandy loam	0.20 inches/inch	0.15 inches/inch	0.05 in/in
6-18"	Sandy clay	0.27 inches/inch	0.23 inches/inch	0.04 in/in

The water retention capacity in the 18 inch depth for this range of tension is:

$$6(0.05) + 12(.04) = .78"$$

The 2.25 inches of AWC represents the differences in the amount of water held between about 0.1 bar and 15 bar tension whereas the 0.78 inches represents the differences in water retention between 0.1 bar and 0.5 bar (the latter being the range measurable by a tensiometer).

Table 2-1. Water Retention Versus Tension for soil-texture groupings 1/

Southern Piedmont Soils

Layer	Soil Texture	Water retention, inch/inch, at tension of- 0.03 bar	0.06 bar	0.25 bar	0.50 bar	0.75 bar	1.0 bar
Surface...	Loamy sand or coarse sandy loam.	0.22	0.17	0.125	0.11	0.105	0.10
Subsoil...	Sandy clay loam, clay loam, or clay.	.36	.34	.32	.30	.....	.29
Surface...	Sandy loam.	.28	.23	.17	.165	.155	.15
Subsoil...	Sand, clay loam, clay loam, or clay.	.36	.34	.32	.30	.....	.29
Surface...	Loam to clay loam.	.35	.34	.32	.31	.30	.295
Subsoil...	Sandy clay loam, clay loam, or clay.	.36	.34	.32	.30	.....	.29

Coastal Plain Soils

Layer	Soil Texture	Water retention, inch/inch, at tension of- 0.025 bar	0.05 bar	0.10 bar	0.25 bar	0.50 bar	1.0 bar
Surface...	Sand and loamy sand.	0.29	0.20	0.13	0.10	0.08	0.07
Subsoil...	Sand and loamy sand.	.29	.20	.13	.10	.08	.07
Surface...	Sand and loamy sand.	.29	.20	.13	.10	.08	.07
Subsoil...	Sandy loam and fine sandy loam.	.31	.26	.20	.17	.15	.13
Surface...	Sand and loamy sand.	.29	.20	.13	.10	.08	.07
Subsoil...	Sandy clay loam and sandy clay.	....	.30	.27	.25	.23	.22
Surface...	Loamy fine sand.	.29	.25	.18	.13	.11	.09
Subsoil...	Sandy clay loam and sandy clay.	....	.30	.27	.25	.23	.22
Surface...	Loamy fine sand.	.29	.25	.18	.13	.11	.09
Subsoil...	Sandy loam and fine sandy loam.	.31	.26	.20	.17	.15	.13
Surface...	Sandy loam and fine sandy loam.	.31	.26	.20	.17	.15	.13
Subsoil...	Sandy clay loam and sandy clay.	....	.30	.27	.25	.23	.22

1/ From Irrigation of Crops in Southeast US ARM 5-9/May 1980 p. 18 and 19.

TEXTURE

Texture is shown for all map units in the SCS Technical Guide, Section II-G, Engineering Interpretations. The following abbreviations are used:

Sand	S
Coarse sand	COS
Fine sand	FS
Loamy coarse sand	LCOS
Loamy sand	LS
Loamy fine sand	LFS
Loamy very fine sand	LVFS
Coarse sandy loam	COSL
Sandy loam	SL
Fine sandy loam	FSL
Very fine sandy loam	VFSL
Loam	L
Silt loam	SIL
Clay loam	CL
Sandy clay loam	SCL
Silty clay loam	SICL
Silty clay	SIC
Sandy clay	SC
Clay	C
Muck or peat	MK or PT

Additional textural modifiers are:

Channery	CN
Gravelly	GR
Shaley	SH

As a guide and quick reference for general planning, estimated available water capacity for selected textures is given in Table 2-2.

Table 2-2. Generalized Available Water Capacity for Selected Textures

Texture	Average AWC (in/in)	Suggested Range in AWC (in/in)
Sand	0.05	0.03 - 0.07
Fine sand	0.06	0.03 - 0.09
Loamy sand	0.08	0.06 - 0.10
Loamy fine sand	0.10	0.07 - 0.13
Sandy loam	0.12	0.09 - 0.15
Fine sandy loam	0.13	0.10 - 0.16
Silt loam	0.18	0.14 - 0.22
Sandy clay loam	0.16	0.13 - 0.19
Clay loam	0.17	0.14 - 0.20
Silty clay loam	0.18	0.14 - 0.22
Sandy clay	0.16	0.13 - 0.19
Clay	0.17	0.14 - 0.20

IRRIGATION RESTRICTIVE FEATURES

Table 2-3 contains a listing of features affecting irrigation. For information on features affecting irrigation for a particular map unit, see the SCS Technical Guide, Section II.

Table 2-3. Features Affecting Irrigation

PROPERTY	LIMITS	RESTRICTIVE FEATURES
1. Fraction >3 in (wt pct) 1/	>25	Large stones
2. Depth to high water table (ft)	<3 +	Wetness Ponding
3. Available water capacity 1/ (in/in)	<0.10	Droughty
4. USDA texture (surface layer)	COS, FS, VFS, LCOS, LS, LFS, LVFS	Fast intake
5. USDA texture (surface layer)	SIC, C, SC	Slow intake
6. Wind erodibility group	1, 2, 3	Soil blowing
7. Permeability (in/hr) (0-60")	<0.2	Percs slowly
8. Depth to bedrock (in)	<40	Depth to rock
9. Depth to cemented pan (in)	<40	Cemented pan
10. Fragipan (great group)	All fragi	Rooting depth
11. Bulk density (g/cm^3) (0-40")	>1.7	Rooting depth
12. Slope (pct)	>3	Slope
13. Erosion factor (K) (surface layer)	>.35	Erodes easily
14. Flooding	Common	Floods
15. Sodium absorption ratio (great group)	>12 (Natric, Halic)	Excess sodium
16. Salinity (mmhos/cm) (0-40")	>4	Excess salt
17. Soil reaction (pH)	<3.6	Too acid

1/ Weighted average to 40 inches.

USDA LAND CAPABILITY CLASSIFICATION SYSTEM

The USDA Land Capability Classification System is a general guide in selection of sites suitable for irrigation systems. The capability groupings are based on the limitations of soils, the risk of damage, and the way soils respond to treatment when used for cropland.

Soils are grouped into eight capability classes from I through VIII. Class I soils have the fewest limitations, widest range of uses and the least risk of damage when row cropped continuously. Soils in higher classes have progressively greater natural limitations.

Within each class of II to VIII, there can be as many as three subclasses designated by the letters "e," "w," or "s." Table 2-4 defines the limitations of each class.

TABLE 2-4. LAND USE CAPABILITY SUBCLASSES

Subclass	Major Limitation
e	Risk of erosion unless a close-growing plant cover is maintained
w	Water in or on the soil interferes with plant growth or cultivation; artificial drainage may eliminate or reduce wetness problems
s	Soils are limited by shallowness, droughty or stony conditions

The subclasses are further divided into capability units. The capability units are similar groups of soils that are suited to the same crops and forage plants. These soils require similar management and have similar yields. Capability units are available through county Soil Conservation Service offices (see S. C. Technical Note Soils-3).

Land used for irrigation and continuous row crops should fall in Classes I - III for best results. Erosion control measures are needed on Class II and Class III with a subclass of "e." Planning and installation for erosion control practices should be done prior to installation of an irrigation system. Wetness problems can be expected on soils with a subclass of "w." Surface and/or subsurface drainage may partially correct wetness problems. Droughty conditions occur on many soils with a subclass of "s." Irrigation will reduce this limitation in many cases. Low fertility, excessive leaching, and erosion problems may also occur on these soils.

Soils with marginal or very little potential for crop production fall in Classes IV-VIII. These soils have severe natural limitations and some may produce low yields under the best management. Irrigation on some Class IV-s land has been successful in the Coastal Plain. This land requires better than average management and the cost per unit of production is generally higher. A careful site by site evaluation is needed before irrigating Class IV-s land.

Land in Classes IV through VIII is normally better suited for hayland, pastureland, woodland, wildlife land or other uses where a permanent cover can be maintained.

The USDA Land Capability Classification System is a useful tool for general planning. Site specific information is necessary to plan the best irrigation system.

EROSION CONTROL

Soil and water conservation needs for an irrigated area may influence the design of an irrigation system. Table 2-5 lists conservation practices that may have the most impact. Other practices including waterways, field ditches, water and sediment control basins, field borders, and filter strips should be considered as appropriate.

TABLE 2-5

Conservation Practice	Major Benefits	Limitations
Contour Farming	-reduction of runoff from low to medium intensity storms -more infiltration of rain and irrigation water -significant reduction of soil loss at minimum cost	-not effective on 3-8% slopes -minimum 4" bed needed for effective water control -row alignment may be difficult to follow on steep or nonuniform slopes -intensive rain or irrigation rates can cause row breakovers and gully erosion
Crop Residue Use	-reduction of wind and water erosion when residue is left on soil surface -increased tilth due to increased organic matter -increases water infiltration, reduce runoff and microorganism activity -reduce evaporation from soil surface	-may require minimum tillage equipment -may not be compatible with all cropping rotations

TABLE 2-5 (Continued)

Conservation Practice	Major Benefits	Limitations
Contour Stripcropping	-similar benefits to contour farming -reduce sediment, reduce runoff, and increase infiltration	-difference crops under the same irrigation system may have different water needs -chemigation generally not feasible -row alignment may not fit large equipment -grassed waterways and pipe outlets may be needed for water control
Terrace Systems	-reduction of runoff which improves water conservation -increase in infiltration -reduction of field sediment loss -enduring conservation practice	-expensive -requires grassed waterways or pipe outlets for water disposal -layout may not fit large equipment -requires annual maintenance
Conservation Tillage	-reduces runoff and sediment loss -increases infiltration and reduces crusting problems -reduces evaporative losses from soil surface -allows more versatile double-cropping systems -effective in wind erosion control	-usually requires specialized equipment -not compatible with all cropping systems -requires expert management and weed control emphasis
Furrow Diking	-reduces ponding in low areas -reduction of runoff and sediment losses -reduced erosion -reduction of wind erosion -can reduce pumping cost due to use of low pressure systems -increase in infiltration	-requires specialized equipment -dikes may interfere with cultural or harvesting operations unless they are plowed out -limited mostly to slopes less than 2 percent or to contouring operations

MAXIMUM IRRIGATION APPLICATION RATES

Sprinkler irrigation application rates and amount should be related to the temporary surface storage available and to a soil's capacity to absorb irrigation water from the surface, and move it into and through the soil profile.

The amount of moisture already in the soil greatly influences the rate at which water enters the soil. The soil takes in and absorbs irrigation water rapidly when water is first applied to the field surface. As the irrigation application continues, the surface soil gradually becomes saturated and the intake rate decreases until it reaches a nearly constant value. Any excess water accumulates for a period of time in soil pores in the surface layer and in surface depressions. When this temporary storage is filled to capacity, runoff begins. Proper management can increase retention time by increasing surface storage capacity on or near the soil surface. A greater amount of excess water is stored, and more time is allowed for water to enter the soil profile. This can be accomplished by several practices including surface residue cover, tillage-induced surface roughness (such as furrow diking), and contour or cross-slope farming. These measures also help to improve infiltration rates and to slow velocity of surface runoff.

The intake of any soil is limited by any restriction to the flow of water into or through the soil profile. The soil layer within the soil water control zone with the lowest transmission rate, either at the surface or directly below it, usually has major effect upon the intake rate. Important general factors that influence intake rates and thus application rates are the physical properties of the soil and, in sprinkler irrigation, the plant cover.

Irrigation application rates in Table 2-6 are to be used as a guide in arriving at maximum application rates for sprinkler applications in South Carolina. The values given are estimates based upon data published in S. C. Agricultural Experiment Station Technical Bulletin 1022, recommendations from NEH-15, Chapter 11, and results and observations obtained from recent irrigation evaluation tests made in South Carolina. Higher application rates may be used with smaller applications due to the higher initial intake rate and surface storage, etc. For trickle systems, see Chapter 7 of the SCS National Engineering Handbook, Section 15 (copy maintained by SCS Engineers), until such time that trickle information is added to this guide.

Table 2-6. Maximum Sprinkler Irrigation Application Rates (In/Hr) For Row Crops 1/

Group No.	Soil Texture in Soil-Water Control Zone	Land Slope (%)	Net Application Depth 0.5"	1.0"	1.5"	2.0"
1	Sand	under 2	2/	2/	3.0	2.0
		2-5	2/	2/	2.5	1.5
		over 5	2/	3.0	2.0	1.0
2	Sand and loamy sand	under 2	2/	3.0	2.0	1.5
		2-5	2/	2.5	1.5	1.0
		over 5	3.0	2.0	1.0	.8
3	Sand and loamy sand over sandy loam or fine sandy loam	under 2	2/	2.0	1.5	1.0
		2-5	3.0	1.5	1.0	.8
		over 5	2.5	1.0	.8	.6
4	Loamy fine sand over sandy loam or fine sandy loam	under 2	3.0	1.5	1.0	.7
		2-5	2.5	1.2	.8	.5
		over 5	2.0	.8	.5	.4
5	Loamy fine sand, or loamy sand over sandy clay loam or sandy clay	under 2	2.0	1.2	.8	.6
		2-5	1.5	.8	.5	.4
		over 5	1.0	.6	.4	.3
6	Sandy loam, fine sandy loam, or loam over sandy clay loam or sandy clay	under 2	1.5	1.0	.6	.5
		2-5	1.0	.6	.5	.4
		over 5	.8	.5	.4	.3
7	Sandy clay loam, loam, silt, or clay loam over silty clay, clay loam, or clay	under 2	1.2	.6	.5	.4
		2-5	.8	.5	.4	.3
		over 5	.5	.4	.3	.2

1/ Use of some cultural practices such as bedding and contouring, row diking, and possibly others may warrant that application rate not be a limiting factor in design. These practices shall be documented to support planning and design.

For grasses or minimum tillage crops with approximately 50% or more ground cover, tabular values may be increased 25%.

For some crops and gun sprinklers, factors other than soil texture, slope, and application depth may dictate that application rates be less than shown. These include but are not limited to crop type, lack of ground cover, droplet impact, and hydrologic condition of the soil. As a guide use approximately 0.8 inch/hour as the maximum allowable gun sprinkler application rate. Adjust lesser values downward as experience dictates.

2/ For soils with these textures, slopes, and application depths, soil intake rates are usually not the limiting factor in system design. Other factors including crop type and droplet impact should be considered to arrive at an application rate. For interpolation between other values in this table, a value of 4.0 inches per hour may be used except for gun sprinklers as noted above.

CHAPTER 3. CROPS

Contents

Tables

CHAPTER 3. CROPS

GENERAL

Most of the irrigated cropland in South Carolina is planted to corn, cotton, and soybeans. Irrigation is of greatest economic importance, however, on specialty or high value crops including vegetables, strawberries, blueberries, tobacco, nurseries, and orchards.

For full benefits from irrigation, other inputs should be supplied in ample amounts. Special attention should be given to proper fertilization; selection of adapted varieties that are capable of producing high yields; control of weeds; insects, and diseases; and use of cultural practices such as row spacing and increased plant population.

Deep soils with low available soil water moisture during periods of peak crop water moisture use commonly show the greatest response to irrigation. Information on the suitability of soils for different crops and for irrigation is provided in the SCS Technical Guides.

Erosion and wetness problems commonly are intensified by irrigation. Consequently, consideration of the physiographic features of the soils is critical to selection of a satisfactory system of irrigation. Conservation tillage, buffer strips of perennial vegetation, vegetated terraces and diversions, contour farming, and grassed waterways are effective erosion control practices which are compatible with most systems of irrigation. Conservation tillage and windbreaks provide effective control of soil blowing. However, attention should be given to height and location of windbreaks so as not to create a barrier to irrigation equipment and cause excessive shading of crops. See Table 2-5 for the major benefits and limitations of soil conservation practices. To drain wet soils, use of subsurface drainage with surface inlets and grassed waterways should be maximized to avoid creating barriers to irrigation.

ROOTING DEPTH AND MOISTURE EXTRACTION

The rooting depth of the crop determines the size of the soil moisture reservoir (soil water control zone) to be managed. The rooting depth depends on the crop being grown and soil conditions. Table 3-1 gives the recommended soil water control zone of common crops grown in most soils in South Carolina. However, examination of crop rooting depths should always be made to determine the proper depths for water management in a particular system. Soils with shallow depths to bedrock, gravel, hardpans, high water tables and other restrictions to root development limit the rooting depth of crops. On these soils, the potential for increased yields and profitability with irrigation is limited by the shallow rooting depth. Because of the limited soil moisture reservoir, these soils require frequent irrigation. The rooting depths on soils with hardpans and on soils with high water tables can be increased by subsoiling and drainage respectively. If the water table is very high over most of the season, a water table management system should be considered since the irrigation requirements would be reduced due to the availability of stored water.

In uniform soils with ample available moisture, plants use water rapidly from the upper part of the root zone and slowly from the lower part. Most plants have similar moisture extraction patterns. The usual extraction pattern for soils with a uniform texture is as follows: about 40 percent from the upper quarter of the root zone, 30 percent from the second quarter of the root zone, 20 percent from the third quarter, and 10 percent from the bottom quarter (see figure 1). Thus, if 50 percent of the total root zone available moisture has been used, the upper portion will be at less than 50 percent available moisture, and the lower portion will be at greater than 50 percent available moisture.

Frequent shallow irrigations will maintain a high moisture level (i.e., low soil moisture tension) in the upper portion of the root zone. If, however, irrigations are scheduled too frequently, excessive evaporation will occur, excessively shallow root zone will result, or, in the extreme, water application depths may be too small to effectively penetrate the crop root zone. With heavy irrigations, losses through runoff, nutrient leeching out of root zone, and risks of overwetting are increased. Thus, a planned method of scheduling irrigation is essential for effective use of irrigation (see Irrigation Water Management Chapter 11 in this Guide for more information on scheduling irrigations).

IRRIGATION AND CROP PRODUCTION

For maximum production and the most efficient use of water, plants must have ample moisture throughout the growing season. For most crops there are critical periods in the growing season when a high moisture level must be maintained for high yields. Except for germination and transplanting, the critical periods are periods of peak moisture use. The peak moisture use period can best be defined as that time when soil moisture stress can most reduce yield in an otherwise healthy crop. This is not the only time in the life of the crop that moisture stress reduces yield, but it is the time when moisture stress has the greatest effect.

If there is enough moisture for germination and for the development of an adequate stand, the critical moisture period is almost always in the latter part of the growing season during the reproductive growth stage. Although plants [illegible] e moisture stress by various symptons, yields will usually be reduced [illegible] time the plants show stress. Time of irrigation should be determined [illegible] examination of the soil moisture content. Maintaining soil moisture [illegible] oisture control zone at or above the 60% level (40% management [illegible] in Chapters 2 and 11 will normally provide adequate [illegible] sandy soils this corresponds generally to main- [illegible] the 35 to 40 centibar range in the middle of the surface layer. For most sandy clay soils in South Carolina, the corresponding tension is in the range of 60 to 80 centibars or greater. Critical moisture periods and specific information for various crops are shown in Table 3-2 at the end of this chapter.

With most crops, maximum yields are attained by maintaining a high soil moisture level along with other needed inputs throughout the growing season. However, more profit may be realized by limiting irrigations to the particular crop's critical moisture use periods in some situations.

Many South Carolina farms have limited water supplies for irrigation. Farmers relying on surface stored water (in ponds) may run short of water during extended dry periods. Selection of crops showing the most response to irrigation and timing irrigation treatments to meet critical water needs of the crop is essential.

Table 3-1. Recommended Soil-Water Control Zone for Selected Mature Crops

Crop	Depth of Soil-Water Control Zone Inches
Corn...........................	18-24
Cotton.........................	18-24
Cucumbers......................	9
Peaches........................	18
Peanuts........................	18
Pecans.........................	18-24
Southern Peas..................	12
Soybeans.......................	18-24
Tomatoes	12
Tobacco	18
Sorghum	18
Watermelon	12
Pasture	24
Alfalfa	24
Blue Berries	12
Strawberries	9
Small Vegetable	9

Note: Depths given are for soils without restrictive layers and for soils with restrictive layers which have been loosened by subsoiling. Use lesser depth as applicable for soils with restrictive layers that limit deep root development. Where two values are given, the depths shown are for Piedmont and Coastal Plains soils respectively.

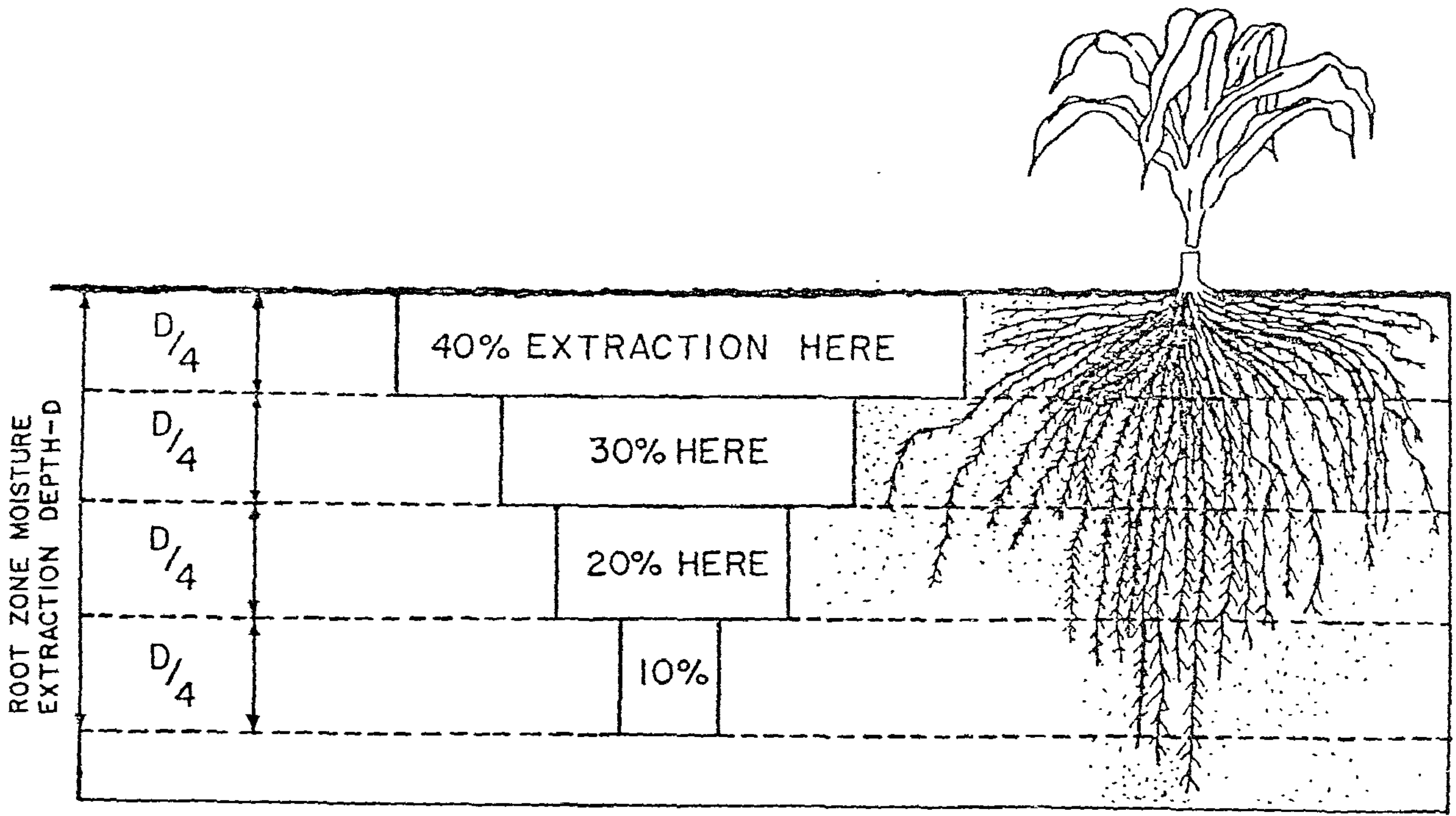


FIGURE 1 AVERAGE MOISTURE-EXTRACTION PATTERN OF PLANTS GROWING IN A SOIL WITHOUT RESTRICTIVE LAYERS AND WITH AN ADEQUATE SUPPLY OF AVAILABLE MOISTURE THROUGHOUT THE ROOT ZONE.

IRRIGATION NEEDS OF SPECIFIC CROPS

ALFALFA

Alfalfa uses a lot of water for high production. However, Clemson University agronomists have found that the length of life of alfalfa is reduced by irrigation without greatly increasing yields. Consequently, irrigation commonly is not recommended. If alfalfa is to be irrigated, the normal procedure is to irrigate 3 to 5 days after each cutting. However, irrigation should also be considered in the early spring before cutting and in the fall. These are critical periods of growth. Thus irrigation at these times will aid in maintenance of a highly productive stand.

BLUEBERRIES

The root system of a blueberry plant begins to grow before the top. If the winter has been dry, irrigation should begin 3 to 4 weeks before the top starts to grow. From bloom until harvest is a critical moisture period for blueberries. After harvest, the blueberry continues to make new growth to support next season's crop. Water and adequate fertility are critical during this stage of growth.

CORN

Corn is shallow rooted until it nears tasseling. Consequently, the effective soil moisture reservoir before tasseling is not as deep as from tasseling to maturity. Demand for water from 60 days to maturity is high, and is especially high and important during the tasseling and grain filling period. During this period, maintaining soil moisture below the 0.25 - 0.4 tension range in medium to coarse textured soils will normally provide adequate water for high yields. While moisture use is high and moisture supply is most critical during this period, moisture stress during any time from germination through maturity can significantly reduce yields. Thus, irrigation schedules should allow for irrigation throughout the life of the corn as needed.

COTTON

Cotton has significant drought tolerance; however, timely irrigation may increase yields considerably. The critical moisture period is from first bloom through boll maturing. High moisture levels after the boll forming stage will delay the crop, increase the amount of immature fibers, and can cause boll rots. High moisture levels early in the season can cause seedling blight and damping off.

GRAPES

The year of planting is a critical moisture period for grapes. After the first year, critical moisture period is during sizing of the fruit.

PEACHES

The fruit growth pattern of peaches is referred to as a double sigmoid growth curve. There is an initial period of rather rapid fruit enlargement followed by a pit hardening period during which fruit enlargement is slight. Finally, the flesh of the fruit thickens, and total enlargement is very rapid. During this final swell, moisture stress reduces yields to the greatest extent.

Research findings are not conclusive on the proper available soil moisture to maintain for peaches. But, data on cling peaches shows that the growth rate during final swell is reduced when the soil moisture tension in the lower portion of the soil-water control zone approaches 5 bars.

Excessive wetness contributes to short life. Thus, the soil moisture tension in the soil-water control zone should not be below about 0.10 bar for any appreciable period of time for sprinkler irrigation when the entire root zone is wetland.

Irrigation recommendations for peaches are similar to those for pecans given in a later section in this chapter. Therefore, refer to the pecan section for more information.

PEANUTS

Peanuts respond well to irrigation with the greatest increases in yield coming on sandy textured soils. Commonly, sprinkler irrigation commenced at 50 percent moisture depletion or less during the peak growing season (beginning at about 80 to 100 days of age) will provide adequate water for high yields. Research results ("Peanut Irrigation in Georgia" by L. E. Samples) with use of tensiometers on a loamy sand indicate sprinkler irrigation should commence when the topsoil tensiometer set at the four inch depth reads 25 centibars (approximately 45 percent depletion of AWC as per Figure A-2 of Appendix A) or more. Tensiometers at the 12 and 20 inch depth would typically each read about 45 centibars in relation to the 25 reading at the 4 inch depth.

Sprinkler irrigation commencing at the 50 percent AWC level is generally recommended to ensure minimum plant stress. Research by Jeff Daniell in Georgia has shown that about 1.5 net inches of water should be applied at each irrigation on most soils utilized for pecans. (Do not exceed the AWC or the intake capacity of the soil, however.)

Drip irrigation research in South Carolina and Georgia (Jim Aitken and Jeff Daniell respectively) indicate that about 2,400 net gallons of water per day per acre should be supplied to mature pecan trees in 12 hours or less at high moisture stress periods. This volume is applicable to a tree canopy area of about 70 to 75 percent or greater. Areas with significantly less tree canopy (as with a young orchard) should be supplied with proportionally less water. Research by Daniell indicates that excess water in the Southeast may decrease yield and pecan quality.

During high moisture stress periods, pan evaporation normally reaches 0.3 to 0.35 inches per day in the Southeast (extreme values as high as 0.5 inches/day were recorded in the summer drought of 1986). A rule of thumb suggested by Daniell for scheduling drip irrigation using pan evaporation is to vary the application amount in proportion to the pan evaporation approximately as follows:

Average Daily Pan Evaporation During Previous Week (inches)	Application Amount (Gallons/Acre/Day)
.33	2,400
.25	1,800
.15	1,100

When approximately 0.5 or more inches of rainfall occur, Daniell recommends turning off the system for 3 days. The system is not turned off if less than 0.5 inches of rain are received.

A method of scheduling drip irrigation recommended by Jim Aitken is to use tensiometers placed 9 inches from 1 GPH emitters in sandy soils at depths from 12 to 24 inches. Aitken's results for young trees on Lakeland sand indicate maximum tree growth with maximum yield and nut quality were obtained by maintaining soil moisture below 5 centibars at the tensiometer locations as compared to the 14 centibar level.

Operators should provide a check on either of the above methods of scheduling by visually observing the trees to note signs of stress and by using the feel and appearance method of determining soil moisture as given in this Guide. These methods used in combination should provide good water management.

Information given in this section for pecans was obtained primarily from publications noted in Appendix E and from personal communications with the authors. Persons giving planning and/or design assistance for pecan irrigation are encouraged to refer to the noted printed materials and utilize applicable information. Also, verbal communication with the authors is encouraged.

SMALL GRAINS

Commonly, small grains are most responsive to irrigations at the preplant and boot stage. However, moderate to high small grain yields can be obtained in

SORGHUM

Grain sorghum is a drought tolerant plant but one that responds well to irrigation. Commonly, the most important irrigation is at preplanting. However, irrigation at the boot to early heading stage can significantly improve yields.

SOYBEANS

Inadequate moisture during germination and early seedling growth can prevent establishment of a uniform stand. However, after establishment of the stand, ARS research has shown little benefit from irrigation until blooming. Soybeans use large amounts of water in the reproductive phase. Particularly during pod growth and seed fill, lack of water will significantly reduce yields. Water stress early in the reproductive stage may result in higher than normal levels of flower abortion, leading to reduced numbers of pods per plant. Moisture deficiencies during the seed filling stage result in smaller than normal seeds.

Research in South Carolina has shown that soybean yields may be enhanced an average of 10 to 15 bushels per acre with irrigation. This assumes good management with non-irrigated yields in the 30-bushel range. For irrigated double-crop soybeans planted behind wheat, yields are predictably five bushels or so below the potential for full season plantings. However, irrigated double-crop yields have consistently been in the 35 to 50-bushel range, depending on the soil and other management factors.

For irrigated full-season soybeans, high-yielding varieties from maturity groups V, VI, and VII are suggested. Varieties with good branching habit and lodging resistance are preferred. When selecting varieties for double cropping under irrigation behind wheat, maturity groups VII and VIII are recommended since they will have more time to develop vegetatively before bloom. Varieties with yield potential and good branching habit and lodging resistance are preferred. Take care to select varieties which have good disease and nematode resistance. Check Extension Circular 545, Soybean Varieties for South Carolina, for details concerning resistance to disease along with suitability for double-cropping and irrigation.

Soybeans should have adequate soil moisture for optimum growth and development through R7 growth stage, which is physiological maturity. This is defined as the stage at which there is one normal pod with mature pod color (e.g. tan) on the main stem. Usually, at least half the leaves have dropped and the remaining leaves are yellow.

In general, other management considerations for irrigated soybeans are not different than for non-irrigated soybeans. Examples are tillage, row spacing, plant population, fertilization, pest management, and harvesting.

J. H. Palmer, Extension Agronomist, Clemson University, Clemson, SC

STRAWBERRIES

The strawberry plant is shallow-rooted with 80-90 percent of its roots in the top 12 inches of soil. In the matted row cultural system, moisture is necessary in the surface soil to permit runner plants to set and make maximum growth. Irrigation is needed at transplanting, during fruit bud formation in the fall and fruit enlargement. Irrigation begun at 50 percent of available soil moisture appears to provide adequate moisture for high yields.

Solid set sprinkler irrigation is recommended as a means of providing frost protection for strawberries in South Carolina. See Chapters 5 and 10 of this guide for more information on frost control applications.

TOBACCO

Irrigation of tobacco at transplanting will greatly improve survival and early growth. An analysis of moisture uptake by tobacco has shown the main moisture uptake zone to be the top 6 inches from transplanting to 3 weeks of age, the top 12 inches during the next two weeks, and 18 inches for the remainder of the growing period. Thus, the depth to which the soil is irrigated should be adjusted for the age of the tobacco. Under limited irrigation, the critical time other than at transplanting is from the knee-high stage until the top leaves are filled out. Light irrigation during harvesting may be needed to avoid premature firing, improve body, and reduce wilting.

Tobacco is especially sensitive to overly wet soils. Thus, the soil moisture tension should not be reduced below 8 to 10 centibars for any appreciable period, i.e. 24 hours. Over-irrigation at early growth stages can increase damage by cool temperatures and limit root development.

VEGETABLES

Vegetables are 80-95 percent water. Consequently, their yield and quality suffer rapidly from drought. Moisture shortages early in the crop's development can delay maturity and reduce yields. Moisture shortages later in the growing season commonly reduce quality and yields.

Most vegetables have small seeds which are planted 3/4 inch deep or less. With the rapid drying of the upper layer of soil, these shallow planted seeds can be left with enough moisture to begin germination but not enough to complete germination. Thus, a poor stand results. Sprinkler irrigation of 1/2 to 3/4 inch immediately after planting will settle the soil and provide adequate moisture for germination. Sprinkler irrigation should be applied slowly to avoid crusting of the surface. For larger seeds, irrigation prior to seeding is desired.

A transplanter will not apply adequate water for vegetable transplants in dry soil. A light sprinkler irrigation of 1/2 to 3/4 inch will provide a ready supply of water for the transplants and will help set the transplants firmly in the soil. Fruits such as tomatoes and peppers are injured by large fluctuations in soil moisture. When soil moisture is not maintained at the proper level, fruit cracking results, yields decrease, and diseases are encouraged.

Research results (ASAE Paper No. 82-2518 by Camp, Robbins, & Karlen) indicate tomato yield and fruit size are enhanced when soil water tension at the lower edge of the soil-water control zone (12 inch depth) is maintained in the 5 to 40 centibar range for a silt soil in the South Carolina coastal plain. (The 40 centibar tension corresponds to approximately the 15 percent depletion level of AWC as per Figure A-2 of Appendix A.) Accordingly, optimun tension range for tomatoes on sandy or clayey soils should be slightly lower or higher respectively. It is important to note however that there is no conclusive data to prove there is one best soil moisture level for tomatoes. It is expected that most other vegetables would respond similiarly to the above noted management schedule for tomatoes.

TABLE 3-2 CRITICAL MOISTURE PERIODS OF MAJOR CROPS

CROP	CRITICAL MOISTURE PERIOD
Alfalfa	Start of flowering and immediately after cutting
Blueberries	When fruit and leaf bud is forming and sizing of the berry
Corn	Tasseling through grain filling
Cotton	First bloom through boll maturing
Fruit trees	Fruit development
Grapes	Sizing of the fruit
Sorghum	Boot, bloom, and dough stages
Pasture	After grazing 1/
Peanuts	First bloom through nut forming
Pecans	During nut set (April-May) and nut fill (August-September)
Small grain	Boot, bloom and early head stage
Soybeans	First bloom to seed enlargement
Strawberries	Bud set and fruit enlargement
Tobacco	Knee high to full bloom 2/
Vegetables	
Beans (Dry, lima, pole, snap)	Flowering
Broccoli	Head development 1/

TABLE 3-2 CRITICAL MOISTURE PERIODS OF MAJOR CROPS (CONT'D.)

ROP	CRITICAL MOISTURE PERIOD
Cabbage	Head development
Carrot	Root expansion 1/
Cantalopes	Flowering and fruit development
Celery	Continuous
Collards	Continuous
Cucumber	Flowering and fruiting
Eggplant	Flowering and fruiting
Greens (turnip and mustard)	Continuous
Lettuce (head)	Head expansion 1/
Okra	Flowering
Onion	Bulbing and bulb expansion 1/
Peas, Green	Flowering
Southern	Flowering and pod swelling
Peppers	Transplanting, flowering up to ½ fruit
Potato, Irish	After flowering
Potato, Sweet	First and last 40 days 2/
Pumpkin	Fruiting
Rutabagas	Root expansion
Squash	Fruit sizing
Tomato	Fruit expansion 2/
Turnip	Root expansion
Watermelon	Fruit expansion

/ Moisture is also critical during seed germination.
/ Moisture is also critical in the seedling and transplanting stages.

S_p and S_r are the plant and row spacings, ft

I_g is the gross depth per irrigation, in

F_i is the irrigation interval (frequency), days

Application Efficiencies

A concept called potential application efficiency (of the low quarter), PE_{lq}, is useful for estimating how well a system can perform. It is a function of the peak use transpiration ratio, T_r, the leaching requirement, LR_t and EU'. When the unavoidable water losses are greater than the leaching water requirements., $T_r > 1/(1.0 - LR_t)$:

$$PE_{lq} = \frac{EU'}{T_r\ (1.0 - LR_t)} \qquad \text{(eq. B-11a)}$$

and where $T_r < 1/(1.0 - LR_t)$:

$$PE_{lq} = EU' \qquad \text{(eq. B-11b)}$$

The values for T_r are given in conjunction with eq. B-8 and LR_t by eq. B-12.

Leaching requirement, LR_t. In arid regions where salinity is a major importance, most of the natural precipitation is accounted for in R_e, W_a, nonbeneficial consumptive use, and/or runoff. There is usually very little additional natural precipitation, D_{rw}, that can add to deep percolation and consequently help satisfy the leaching requirements. Furthermore, since only a portion of the soil area is wetted and needs leaching under trickle irrigation, the effective additional precipitation is reduced to $(P_w/100)\ D_{rw}$; therefore, it can almost always be neglected. P_w is the average horizontal area wetted in the top part (6 to 12 in) of the crop root zone as a percentage of the total crop area.

Calculating the leaching requirement for trickle irrigation, LR_t is greatly simplified by neglecting $(P_w/100)D_{rw}$ and

$$LR_t = \frac{L_n}{I_n} = \frac{L_N}{I_N} = \frac{EC_w}{EC_{dw}}$$

in which

LR_t is the leaching requirement under

L_n and L_N are the net per irrigation a
requirements, in

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 4. IRRIGATION WATER REQUIREMENTS

GENERAL

Water requirements for irrigation are based on several factors including the crop, climatic factors, soil texture and fertility, and the quality of irrigation water. The method of irrigation also affects water requirements by changing the efficiency and perhaps the consumptive use rate (trickle irrigation).

Soils and crops are respectively covered in Chapters 2 and 3. Climatic factors and water quality concerns are included in this chapter.

CONSUMPTIVE WATER USE AND IRRIGATION NEEDS

CLIMATIC ZONES

Several climatic factors influence the quantity of water needed for irrigation. Because of the effects of climate and the variation of climate, crops, and planting dates within the state, South Carolina was divided into three climatic zones. These zones are shown on page 4-6.

MODIFICATIONS FOR TRICKLE IRRIGATION SYSTEMS

Trickle irrigation systems are designed and managed to deliver light, frequent applications of water that wet only a portion of the soil. The irrigation procedures given in Chapters 2 and 3 of this Guide must be adjusted for trickle application. To meet the objective of trickle irrigation, water application is based on moisture replacement in a small area of the soil. This requires determining the wetted area, wetting pattern, and vertical and horizontal water movement in the soil. The values of water requirements, consumptive use, and frequency of irrigation are adjusted accordingly. See Chapter 10-D of this Irrigation Guide and Chapter 7 of the SCS National Engineering Handbook, Section 15 (copy maintained by SCS Engineers), for detailed procedures for trickle irrigation.

CONSUMPTIVE USE

Consumptive use is the amount of water required to meet evapotranspirati needs so that plant production is not limited due to lack of water. Evapotranspiration and consumptive use are usually expressed in inches ; day (in./day) and are used interchangeably in this publication.

The consumptive use of crops in this Guide has been calculated by criter given in SCS Technical Release 21, dated April 1967 and revised Septembe 1970. Normal monthly temperature, precipitation, and annual rainfall f period 1951-1980 were used as input data to determine water requirement various crops. Table 4-2 lists the average monthly, and seasonal

consumptive use of crops and effective rainfall for the different zones and irrigation water needs based upon 0.75 inches net depth of applications. Slight adjustments may be made for net application depths other than 0.75 inch, but for normal use (0.5 inch to 1.5 inches applied) no adjustments are required.

Input data used in calculating values for the tables in this chapter are in the appendix. Because South Carolina is located in the humid region, the seasonal consumptive-use coefficient (K) used for each crop was the lower value given in Table 2 of SCS Technical Release 21 (Revised September 1970).

EFFECTIVE RAINFALL

Effective rainfall is that portion of the total rainfall which does not evaporate, run off, or percolate below the root zone and is available to the plant to meet its consumptive use requirements.

Since there are no effective rainfall records available, total rainfall records are used and an estimate made of the percent of the total which is effective.

NET IRRIGATION APPLICATION

The net irrigation application is dependent upon the capacity of the soil profile in the root zone to store available moisture and the moisture deficit allowed. The moisture deficit is the percent of the total available moisture in the soil that evapotranspiration is allowed to remove before it is replaced by irrigation. Usually this amount is 40-50%.

Research has shown that irrigating when the moisture deficit is only 40% may significantly increase yields above that of a 50% deficit for some crops.

Net Irrigation Application =

(available soil moisture in the managed root zone) X percent deficit managed.

Example: 2.0 inches X 0.40 = 0.80 inches

GROSS IRRIGATION APPLICATION

The gross irrigation application is the net irrigation application plus the water "wasted" due to evaporation, deep percolation, non-uniform distribution, etc.

$$\text{Gross Irrigation Application} = \frac{\text{Net Irrigation Application}}{\text{Irrigation Efficiency (usually 70-80\%)}}$$

$$\text{Example: } \frac{0.8 \text{ inches}}{0.70} = 1.14 \text{ inches}$$

The irrigation system must pump 1.14 inches of water to get 0.8 inches of water to the managed root zone.

IRRIGATION EFFICIENCY

The irrigation (system) efficiency is defined as the product of the application eff. x pattern eff. where

$$\text{application eff.} = \frac{\text{weighted average catch (system) x 100}}{\text{Gross Application}}$$

and

$$\text{pattern eff.} = \frac{\text{weighted average (Low 25\%) x 100}}{\text{Weighted Average (System)}}$$

PRE-IRRIGATION REQUIREMENTS

All values given in this chapter assume that the soil is at field capacity at the beginning of the growing season. For most of South Carolina, this is true in the early spring but late season crops may need irrigation before or shortly after planting to bring the soil moisture up to field capacity. This irrigation is not included in the values in this chapter.

PEAK CONSUMPTIVE USE RATE

The peak consumptive use rate is the highest daily amount of evapotranspiration that a crop has during its growing season. It is measured in inches per day. The duration of this peak may be days or weeks.

Design peak use rates are values based on the peak consumptive use rates from TR-21, research information, or various other state guides.

The design peak use rates should be used to determine the required flow capacity of the system. These rates are shown in the table 4-1.

IRRIGATION FREQUENCY

Irrigation frequency refers to the number of days from the beginning of one irrigation cycle to the beginning of the next cycle, assuming no effective rainfall between irrigations.

Example: Irrigate when 40% of the available moisture is depleted.
Available moisture in the root zone (18 in.) is 2.0 inches.
Crop: Corn, Peak daily consumptive use 0.33 in.

$$\text{Irrigation Frequency} = \frac{\text{Net Irrigation Application}}{\text{Peak Daily Consumptive Use}}$$

$$\text{Irrigation Frequency} = \frac{0.4\text{x}2.0 \text{ in.}}{0.33 \text{ in./day}} = 2.42 \text{ days or 2 days and 10 hours}$$

This means that with no effective rainfall the system must be started at the beginning point every 2 days and 10 hours. When the use rate is less than th peak period use, the irrigation cycle will be longer.

IRRIGATION PERIOD

The irrigation period is the time that it takes the system to complete one irrigation cycle on the designed area. The irrigation period should be less than the irrigation frequency to allow for regular equipment maintenance and the repair of equipment breakdowns.

SEASONAL NET IRRIGATION REQUIREMENT

The seasonal net irrigation requirement is the amount of water needed to satisfy crop consumptive use requirements in excess of the effective rainfall during the growing season. This amount is expressed in inches and is given in the tables in this chapter. These values are computed using the TR-21 computer program based upon an 80% chance of occurrence of effective rainfall. If actual planting dates differ significantly from those indicated in the tables, water use and irrigation requirements within each month must be adjusted accordingly.

SEASONAL GROSS IRRIGATION REQUIREMENT

The seasonal gross irrigation requirement is the amount of water that must be pumped during the growing season to get the net irrigation requirement in the root zone.

$$\text{Seasonal Gross Irrigation Requirement} = \frac{\text{Net Irrigation Requirement}}{\text{Irrigation Efficiency}}$$

The values given in the tables in this chapter are based on 70% irrigation system efficiency and should provide an adequate water supply 8 out of 10 years on an average. (Measurement of overall system efficiencies of several centerpivot systems in South Carolina yielded efficiencies ranging from 32 to 76 percent with an average near 70. System efficiency is defined as the product of application eff. x pattern eff.)

IRRIGATION STORAGE REQUIREMENTS

In computing the required water storage volume for irrigation, the number of irrigations desired, the gross irrigation amount per application, recharge, insoak, and evaporation must be considered. Measurements of recharge should be during a dry period of the irrigation season if possible.

EXAMPLE COMPUTATIONS

Example No. 1:
Crop - 100 acres of corn for grain in Newberry County, South Carolina, planted in period 3/10 to 4/21 to be irrigated by sprinkler irrigation. Assume system efficiency = 70 percent.

Determine the following:

Climatic Zone - from page 4-6 = Zone 1

Design peak use rate - from page 4-7 = 0.30 inches/day

Seasonal gross irrigation requirement from page 4-8 = 16.2 inches.

Seasonal gross storage requirement needed to be available for irrigation

$$\frac{100 \text{ ac.} \times 16.2 \text{ inches}}{12 \text{ in./ft.}} = \underline{\quad 135 \quad} \text{ acre feet}$$

Seasonal gross storage volume needed assuming 80% efficiency of the storage reservoir $= \frac{135}{.8} = \underline{169}$ acre ft.

Find the pumping rate needed if irrigating 18 hours/day during the peak use period -

$$Q = \frac{453\ AD}{H}$$

Where Q = flow rate, gallons/min. (GPM)
A = Area irrigated = 100 ac.
D = Peak use rate/ eff.=0.30/0.7=0.43
H = Hours of pumping = 18

$$= \frac{453(100)(0.43)}{18}$$

$$= \underline{\quad 1082 \quad} \text{ GPM}$$

Example No. 2: Same system as example 1. Assume only a two week supply of water is desired by the landowner to be available during the peak use period. Find the gross storage needed assuming 80% efficiency of the storage reservoir.

$$\text{Volume} = \frac{(100 \text{ acres}) \times (0.43 \text{ inch/day}) \times (14 \text{ days})}{(0.80)\ 12 \text{ in./ft.}} = \underline{63} \text{ ac. ft.}$$

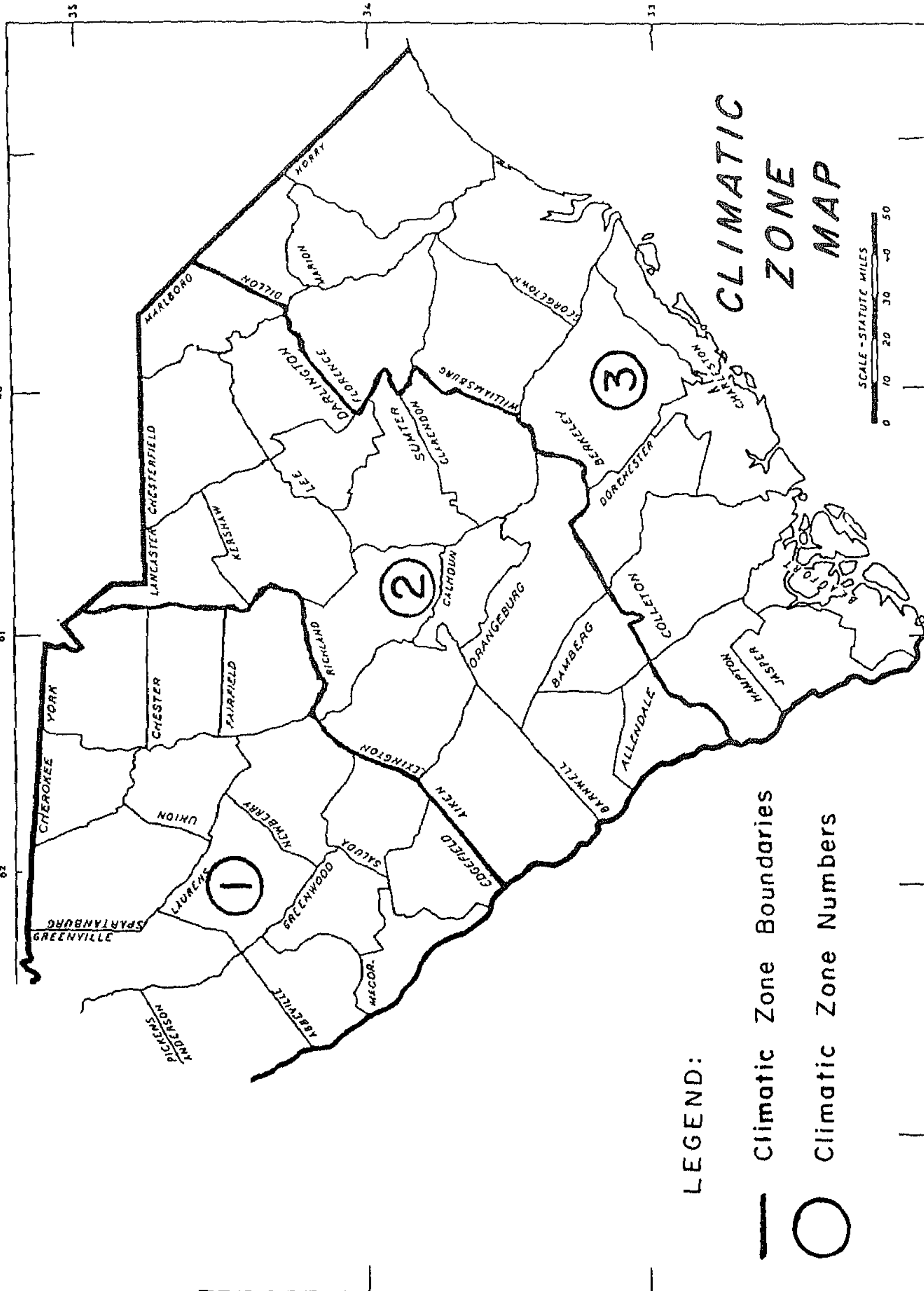

CLIMATIC ZONE MAP
SCALE - STATUTE MILES
0 10 20 30 40 50
LEGEND:
Climatic Zone Boundaries
Climatic Zone Numbers
1
2
3
CHEROKEE
YORK
CHESTER
FAIRFIELD
LANCASTER
CHESTERFIELD
MARLBORO
DILLON
MARION
HORRY
DARLINGTON
FLORENCE
KERSHAW
LEE
SUMTER
CLARENDON
WILLIAMSBURG
GEORGETOWN
BERKELEY
CHARLESTON
DORCHESTER
COLLETON
RICHLAND
CALHOUN
ORANGEBURG
BAMBERG
LEXINGTON
AIKEN
BARNWELL
ALLENDALE
HAMPTON
JASPER
BEAUFORT
UNION
NEWBERRY
LAURENS
SALUDA
GREENWOOD
EDGEFIELD
MCCOR.
ABBEVILLE
SPARTANBURG
GREENVILLE
PICKENS
ANDERSON

Figure 4-1

Recommended Design Peaks For South Carolina Crops

Table 4-1. Recommended Design Peaks For South Carolina Crops

Cultivated Row Crops	Inches/Day
Corn (includes silage)	.30
Cotton	.30
Soybeans	.30
Grain Sorghum	.28
Peanuts	.25
Tobacco	.21
Sunflowers	.21
Small Grains	.20
Vegetables	
Onions, Lettuce	.13
Cabbage, Turnips, Greens	.13
Strawberries	.15
Cucumbers, Cantaloupes, Squash, Snap beans, Peppers, Eggplant, Watermelon, Okra	.18
Sweet Corn	.28
Sweet Potatoes	.23
Tomatoes	.26
Orchard Crops[1]	
Apples	.24
Peaches, Plums	.24
Pecans, Walnuts	.24
Hay and Forage Crops	
Alfalfa	
Pasture Grasses	
Winter annuals	

[1]For trickle irrigation of these orchard crops, only 2,400 gallons per acre applied daily within the root zone area are recommended for the design peak. This is equivalent to approximately 0.13 inches/day/acre at 70 percent coverage by tree canopy. [i.e., 2,400/(0.7 x 27,154) = 0.126 in/day].

Consumptive Use and Irrigation Water Requirements

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 1

Crop	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
Corn, Grain	4/1	7/20	April	1.91	1.17	0	0
			May	4.94	1.74	3.19	4.6
			June	7.03	1.99	5.04	7.2
			July	4.44	1.36	3.08	4.4
			Season Totals	18.32	6.26	11.31	16.2
Corn, Silage	4/1	7/20	April	1.81	1.11	0	0
			May	4.47	1.70	2.73	3.9
			June	7.15	2.00	5.15	7.4
			July	4.89	1.41	3.47	5.0
			Season Totals	18.32	6.22	11.35	16.3
Corn, Sweet	4/1	6/30	April	2.05	1.22	.08	.1
			May	5.46	1.80	3.66	5.2
			June	7.03	1.99	5.04	7.2
			Season Totals	14.54	5.00	8.78	12.5
Soybeans, Early	5/10	9/30	May	.97	.60	0	0
			June	2.82	1.52	.93	1.3
			July	5.61	1.96	3.65	5.2
			August	7.60	1.99	5.61	8.0
			September	4.57	1.74	2.83	4.0
			Season Totals	21.57	7.81	13.02	18.6
Soybeans, Late	6/10	10/28	June	1.29	.79	0	0
			July	3.50	1.75	1.50	2.1
			August	5.89	1.81	4.07	5.8
			September	6.31	1.91	4.40	6.3
			October	2.88	1.08	1.08	2.6
			Season Totals	19.87	7.35	11.77	16.8
Small Vegetables	2/20	4/21	February	.21	.13	0	0
			March	2.63	1.61	.35	.5
			April	2.60	1.13	1.48	2.1
			Season Totals	5.44	2.86	1.83	2.6
Small Vegetables	3/20	5/19	March	.42	.26	0	0
			April	3.58	1.60	1.39	2.0
			May	2.68	1.03	1.64	2.3
			Season Totals	6.67	2.89	3.04	4.3
Small Vegetables	4/20	6/19	April	.52	.32	0	0
			May	4.47	1.70	2.22	3.2
			June	2.95	1.10	1.85	2.6
			Season Totals	7.94	3.12	4.07	5.8

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 1

Crop	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
Small Vegetables	4/20	7/19	April	.44	.27	0	0
			May	3.70	1.62	1.50	2.1
			June	5.57	1.83	3.74	5.3
			July	2.72	1.13	1.59	2.3
			Season Totals	12.44	4.86	6.83	9.7
Small Vegetables	8/1	10/15	August	3.94	1.58	1.61	2.3
			September	4.42	1.72	2.70	3.9
			October	.97	.54	.43	0.6
			Season Totals	9.32	3.84	4.73	6.8
Tomatoes	5/1	8/29	May	2.27	1.30	.22	.3
			June	4.47	1.72	2.74	3.9
			July	6.92	2.11	4.81	6.9
			August	4.93	1.64	3.29	4.7
			Season Totals	18.59	6.77	11.07	15.8
Sorghum	6/1	9/30	June	2.89	1.53	.61	.9
			July	6.96	2.12	4.84	6.9
			August	6.57	1.88	4.68	6.7
			September	3.45	1.63	1.82	2.6
			Season Totals	19.86	7.16	11.95	17.1
Peanuts	5/1	9/18	May	1.06	.65	0	0
			June	4.21	1.70	2.17	3.1
			July	7.87	2.23	5.64	8.1
			August	4.32	1.66	2.66	3.8
			September	.54	.33	.21	.3
			Season Totals	17.99	6.56	10.68	15.3
Wheat	11/1	5/31	November	2.34	1.		
			December	.62	.		
			January	0	(		
			February	.99	.		
			March	3.76	2.		
			April	5.28	1.		
			May	2.56	1.		
			Season Totals	15.55	7.		
Snap Beans	4/20	6/19	April	.54	.		
			May	3.61	1.		
			June	3.78	1.		
			Season Totals	7.94	3.		

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 1

Crop	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
Grapes	4/1	9/15	April	1.38	.84	0	0
			May	2.97	1.55	1.20	1.7
			June	4.20	1.70	2.50	3.6
			July	4.73	1.87	2.86	4.1
			August	4.16	1.64	2.52	3.6
			September	1.35	.82	.52	.7
			Season Totals	18.79	8.43	9.61	13.7
Pasture Grasses	3/15	9/15	March	.87	.53	0	0
			April	3.10	1.56	1.14	1.6
			May	4.80	1.73	3.07	4.4
			June	6.05	1.88	4.17	6.0
			July	6.77	2.10	4.68	6.7
			August	6.19	1.84	4.34	6.2
			September	2.23	1.31	.92	1.3
			Season Totals	30.01	10.95	18.32	26.2
Alfalfa	3/15	9/15	March	.91	.56	0	0
			April	3.22	1.57	1.26	1.8
			May	5.18	1.77	3.41	4.9
			June	6.64	1.95	4.69	6.7
			July	7.30	2.16	5.14	7.3
			August	6.50	1.88	4.62	6.6
			September	2.27	1.32	.95	1.4
			Season Totals	32.01	11.19	20.07	28.7
Pecans & Walnuts	4/1	10/10	April	1.35	.83	0	0
			May	3.25	1.59	1.44	2.1
			June	5.37	1.81	3.56	5.1
			July	6.45	2.06	4.39	6.3
			August	5.31	1.76	3.56	5.1
			September	3.13	1.60	1.53	2.2
			October	.46	.28	.18	.3
			Season Totals	25.32	9.92	14.65	20.9
Deciduous Orchards (w/o cover)	3/20	6/15	March	.32	.20	0	0
			April	2.29	1.32	.35	.5
			May	4.63	1.71	2.92	4.2
			June	3.21	1.60	1.60	2.3
			Season Totals	10.45 1/	4.83	4.87	7.0
Deciduous Orchards (w/o cover)	3/20	7/15	March	.28	.17	0	0
			April	2.00	1.22	.13	.2
			May	4.05	1.66	2.39	3.4
			June	5.60	1.84	3.76	5.4
			July	3.01	1.70	1.32	1.9
			Season Totals	14.94 1/	6.58	7.60	10.9

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 1

Crop	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
Deciduous Orchards (w/o cover)	3/20	8/15	March	.27	.16	0	0
			April	1.89	1.16	.09	.1
			May	3.84	1.64	2.20	3.1
			June	5.31	1.81	3.50	5.0
			July	5.90	2.00	3.91	5.6
			August	2.28	1.31	.97	1.4
			Season Totals	19.49 1/	8.07	10.67	15.2
Apples	3/20	9/15	March	.27	.17	0	0
			April	1.93	1.18	.11	.2
			May	3.91	1.64	2.27	3.2
			June	5.42	1.82	3.60	5.1
			July	6.02	2.01	4.01	5.7
			August	4.81	1.71	3.11	4.4
			September	1.22	.75	.47	.7
			Season Totals	23.59	9.27	13.57	19.4
Strawberries	3/20	5/19	March	.42	.26	0	0
			April	3.58	1.60	1.39	2.0
			May	2.68	1.03	1.64	2.3
			Season Totals	6.67	2.89	3.04	4.3
Cotton	4/20	9/20	April	.26	.16	0	0
			May	1.62	.99	0	0
			June	4.45	1.72	2.70	3.9
			July	7.15	2.14	5.01	7.2
			August	5.63	1.79	3.84	5.5
			September	1.99	1.06	.93	1.3
			Season Totals	21.09	7.85	12.49	17.9

1/ Use 0.14 inches per day after maturity through September.

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 2

rop	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
orn, Grain	3/20	7/8	March	.44	.27	0	0
			April	2.63	1.26	.79	1.1
			May	5.99	1.77	4.22	6.0
			June	6.98	2.24	4.73	6.8
			July	1.77	.63	1.14	1.6
			Season Totals	17.80	6.18	10.88	15.5
Corn, Silage	3/20	7/8	March	.42	.26	0	0
			April	2.40	1.24	.58	.8
			May	5.64	1.74	3.90	5.6
			June	7.39	2.30	5.09	7.3
			July	1.96	.66	1.30	1.9
			Season Totals	17.80	6.19	10.87	15.5
Corn, Sweet	3/20	6/18	March	.45	.27	0	0
			April	2.99	1.30	1.11	1.6
			May	6.23	1.80	4.43	6.3
			June	4.34	1.37	2.98	4.3
			Season Totals	14.01	4.74	8.52	12.2
Soybeans	5/1	9/20	May	1.59	.97	0	0
			June	3.35	1.83	1.39	2.0
			July	6.63	2.42	4.21	6.0
			August	7.46	2.34	5.12	7.3
			September	2.91	1.11	1.80	2.6
			Season Totals	21.93	8.65	12.53	17.9
Soybeans	6/10	10/28	June	1.31	.80	0	0
			July	3.53	1.96	1.33	1.9
			August	5.92	2.14	3.78	5.4
			September	6.46	1.87	4.59	6.6
			October	3.02	.96	2.06	2.9
			Season Totals	20.24	7.73	11.77	16.8
Small Vegetables	2/20	4/21	February	.22	.14	0	0
			March	2.79	1.62	.51	.7
			April	2.66	.96	1.70	2.4
			Season Totals	5.67	2.71	2.21	3.2
Small Vegetables	3/20	5/19	March	.45	.27	0	0
			April	3.71	1.36	1.78	2.5
			May	2.74	1.00	1.74	2.5
			Season Totals	6.90	2.63	3.52	5.0

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 2

Crop	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
Small Vegetables	4/20	6/19	April	.55	.33	0	0
			May	4.61	1.64	2.44	3.5
			June	2.97	1.25	1.72	2.4
			Season Totals	8.14	3.22	4.17	6.0
Small Vegetables	4/20	7/19	April	.47	.28	0	0
			May	3.84	1.57	1.71	2.4
			June	5.65	2.08	3.57	5.1
			July	2.75	1.31	1.43	2.0
			Season Totals	12.71	5.25	6.71	9.6
Small Vegetables	8/1	10/15	August	3.97	1.87	1.34	1.9
			September	4.53	1.68	2.85	4.1
			October	1.01	.48	.54	.8
			Season Totals	9.51	4.03	4.73	6.8
Tomatoes	4/20	8/18	April	.55	.33	0	0
			May	2.69	1.41	.75	1.1
			June	5.59	2.08	3.51	5.0
			July	6.80	2.44	4.36	6.2
			August	2.94	1.19	1.76	2.5
			Season Totals	18.57	7.44	10.38	14.8
Peanuts	4/20	9/7	April	.10	.06	0	0
			May	1.95	1.19	.05	.1
			June	5.46	2.06	3.40	4.9
			July	7.88	2.59	5.29	7.6
			August	2.69	1.62	1.07	1.5
			September	.14	.09	.06	.1
			Season Totals	18.23	7.61	9.86	14.1
Grapes	3/15	8/31	March	[illegible]	[illegible]	[illegible]	[illegible]

4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 2

	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
is	4/10	6/9	April	1.32	.78	0	0
			May	4.54	1.63	2.69	3.8
			June	1.91	.65	1.26	1.8
			Season Totals	7.76	3.07	3.94	5.6
	5/15	9/15	May	1.01	.61	0	0
			June	4.82	1.99	2.47	3.5
			July	7.71	2.57	5.14	7.3
			August	5.58	2.10	3.48	5.0
			September	1.58	.78	.81	1.2
			Season Totals	20.70	8.05	11.90	17.0
	3/15	9/15	March	.96	.58	0	0
			April	3.28	1.33	1.58	2.3
			May	4.99	1.68	3.31	4.7
			June	6.13	2.14	4.00	5.7
			July	6.83	2.44	4.39	6.3
			August	6.22	2.18	4.04	5.8
			September	2.27	1.30	.97	1.4
			Season Totals	30.68	11.65	18.29	26.1
	3/1	8/31	March	1.91	1.16	0	0
			April	3.47	1.34	2.13	3.0
			May	5.49	1.73	3.77	5.4
			June	6.87	2.23	4.64	6.6
			July	7.51	2.54	4.97	7.1
			August	6.66	2.23	4.43	6.3
			Season Totals	31.90	11.23	19.92	28.5
	3/20	9/30	March	.19	.12	0	0
			April	1.50	.90	0	0
			May	3.44	1.54	1.83	2.6
			June	5.54	2.07	3.47	5.0
			July	6.62	2.42	4.20	6.0
			August	5.43	2.08	3.35	4.8
			September	3.25	1.56	1.69	2.4
			Season Totals	25.97	10.68	14.54	20.8
	3/10	6/5	March	.76	.46	0	0
			April	2.73	1.27	1.00	1.4
			May	5.44	1.72	3.72	5.3
			June	1.22	0.74	0.48	0.7
			Season Totals	10.15 1/	4.20	5.20	7.4
	3/10	7/5	March	.63	.38	0	0
			April	2.28	1.22	.55	.8
			May	4.54	1.63	2.90	4.1
			June	6.13	2.14	3.99	5.7
			July	1.09	0.67	0.43	0.6
			Season Totals	14.67 1/	6.04	7.88	11.2

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 2

Crop	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gro[illegible]
Deciduous Orchards (w/o cover)	3/10	8/5	March	.58	.35	0	
			April	2.08	1.20	.36	
			May	4.14	1.60	2.55	[illegible]
			June	5.60	2.08	3.52	[illegible]
			July	6.19	2.36	3.83	[illegible]
			August	0.79	0.48	0.31	[illegible]
			Season Totals	19.39 1/	8.06	10.57	[illegible]
Strawberries	3/10	5/10	March	1.21	.74	0	
			April	4.10	1.39	2.43	[illegible]
			May	1.13	.46	.68	[illegible]
			Season Totals	6.44	2.58	3.11	[illegible]
Cotton	4/20	9/20	April	.27	.17	0	
			May	1.70	1.03	.02	
			June	4.54	1.96	2.58	[illegible]
			July	7.26	2.50	4.75	[illegible]
			August	5.69	2.11	3.58	[illegible]
			September	2.04	1.03	1.02	
			Season Totals	21.50	8.80	11.95	[illegible]
Watermelons	3/25	7/12	March	.23	.14	0	
			April	2.26	1.22	.38	
			May	4.54	1.63	2.91	
			June	5.30	2.04	3.25	
			July	2.90	.87	1.21	
			Season Totals	14.41	5.91	7.75	[illegible]

1/ Use 0.14 inches per day after maturity through September.

e 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 3

	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
ain	3/10	6/29	March	.94	.58	0	0
			April	3.28	1.16	1.74	2.5
			May	6.36	1.89	4.47	6.4
			June	6.56	2.28	4.28	6.1
			July	0	0	0	0
			Season Totals	17.15	5.91	10.49	15.0
ilage	3/10	6/29	March	.90	.55	0	0
			April	2.93	1.14	1.39	2.0
			May	6.22	1.87	4.34	6.2
			June	7.10	2.36	4.75	6.8
			Season Totals	17.15	5.91	10.48	15.0
Sweet	3/10	6/8	March	1.00	.61	0	0
			April	3.79	1.19	2.24	3.2
			May	6.47	1.90	4.57	6.5
			June	1.97	.65	1.32	1.9
			Season Totals	13.23	4.35	8.13	11.6
m	5/15	9/15	April	1.00	.61	0	0
			May	4.79	2.11	2.32	3.3
			June	7.64	2.83	4.81	6.9
			July	5.58	2.40	3.17	4.5
			August	1.61	.88	.73	1.0
			Season Totals	20.62	8.83	11.03	15.8
ans	5/1	9/20	May	1.58	.96	0	0
			June	3.32	1.89	1.29	1.8
			July	6.57	2.66	3.90	5.6
			August	7.44	2.66	4.77	6.8
			September	2.95	1.26	1.69	2.4
			Season Totals	21.85	9.44	11.66	16.7
eans,	6/10	10/28	June	1.29	.79	0	0
			July	3.47	2.06	1.17	1.7
			August	5.86	2.44	3.42	4.9
			September	6.51	2.12	4.39	6.3
			October	3.12	1.05	2.06	2.9
			Season Totals	20.25	8.46	11.05	15.8
ll etables	9/1	11/15	September	3.52	1.75	1.03	1.5
			October	3.58	1.17	2.40	3.4
			November	.77	.38	.39	.6
			Season Totals	7.88	3.30	3.82	5.5

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 3

Crop	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
Small Vegetables	2/15	4/16	February	.47	.28	0	0
			March	3.10	1.66	.87	1.2
			April	1.94	.63	1.31	1.9
			Season Totals	5.51	2.58	2.18	3.1
Small Vegetables	2/15	5/16	February	.36	.22	0	0
			March	2.48	1.43	.44	.6
			April	4.22	1.22	3.00	4.
			May	2.15	.86	1.29	1.8
			Season Totals	9.22	3.73	4.74	6.8
Small Vegetables	2/15	6/15	February	.31	.19	0	0
			March	1.98	1.21	.14	.
			April	3.90	1.20	2.70	3.
			May	5.22	1.77	3.44	4.
			June	2.06	1.02	1.05	1.
			Season Totals	13.46	5.38	7.33	10.
Small Vegetables	3/1	4/30	March	2.18	1.29	.14	.
			April	3.88	1.20	2.68	3.
			Season Totals	6.05	2.48	2.82	4.
Small Vegetables	3/1	5/30	March	1.65	1.01	0	0
			April	3.99	1.20	2.67	3.
			May	4.43	1.65	2.78	4.
			Season Totals	10.06	3.86	5.45	7.
Small Vegetables	3/1	6/29	March	1.33	.81	0	0
			April	3.42	1.17	2.02	2.
			May	5.29	1.78	3.51	5.
			June	4.48	2.03	2.45	[illegible]
			Season Totals	14.52	5.79	7.99	
Small Vegetables	8/1	10/15	August				
			September				
			October				
			Season Totals				
Tomatoes	3/1	6/29	March				
			April				
			May				
			June				
			Season Totals				

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 3

Crop	Date Plant	Date Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements Net	Irrigation Requirements Gross
Tomatoes	4/20	8/18	April	.55	.31	0	0
			May	2.69	1.45	.73	1.0
			June	5.55	2.20	3.35	4.8
			July	6.75	2.69	4.06	5.8
			August	2.94	1.36	1.59	2.3
			Season Totals	18.48	8.01	9.72	13.9
Peanuts	4/20	9/7	April	.10	.06	0	0
			May	1.95	1.19	.05	.1
			June	5.43	2.19	3.24	4.6
			July	7.83	2.86	4.97	7.1
			August	2.69	1.64	1.05	1.5
			September	.15	.09	.06	.1
			Season Totals	18.15	8.03	9.37	13.4
Grapes	3/15	8/31	March	.35	.22	0	0
			April	1.57	.88	.08	.1
			May	3.21	1.58	1.63	2.3
			June	4.41	2.07	2.34	3.3
			July	4.94	2.43	2.51	3.6
			August	4.35	2.24	2.11	3.0
			Season Totals	18.83	9.42	8.67	12.4
Winter Wheat	11/1	5/31	November	1.98	.86	.36	.5
			December	3.03	1.25	1.77	2.5
			January	2.50	1.28	1.22	1.7
			February	2.80	1.37	1.43	2.0
			March	4.58	1.81	2.77	4.0
			April	4.78	1.26	3.52	5.0
			May	1.93	1.18	.75	1.1
			Season Totals	21.59	9.02	11.83	16.9
Snap Beans	4/1	5/31	April	2.21	1.06	.40	.6
			May	5.19	1.77	3.42	4.9
			Season Totals	7.40	2.83	3.82	5.5
Pasture Grasses	3/15	9/15	March	.98	.60	0	0
			April	3.27	1.16	1.74	2.5
			May	4.97	1.75	3.23	4.6
			June	6.09	2.27	3.82	5.5
			July	6.77	2.69	4.08	5.8
			August	6.20	2.49	3.71	5.3
			September	2.31	1.38	.93	1.3
			Season Totals	30.60	12.34	17.51	25.0

Table 4-2. Consumptive Use and Irrigation Water Requirements - Inches
Climatic Zone 3

Crop	Date: Plant	Date: Maturity	Month	Consumptive Use	Effective Rainfall	Irrigation Requirements: Net	Irrigation Requirements: Gross
Cotton	4/20	9/20	March	.27	.17	0	0
			April	1.69	1.03	.02	.03
			May	4.50	2.08	2.42	3.5
			June	7.19	2.76	4.44	6.3
			July	5.68	2.42	3.27	4.7
			August	2.08	1.17	.91	1.3
			Season Totals	21.43	9.62	11.06	15.8
Pecans and Walnuts	3/10	9/30	March	.38	.23	0	0
			April	1.54	.86	.08	.1
			May	3.53	1.61	1.92	2.7
			June	5.65	2.22	3.43	4.9
			July	6.74	2.69	4.05	5.8
			August	5.57	2.40	3.17	4.5
			September	3.39	1.78	1.62	2.3
			Season Totals	26.80	11.79	14.26	20.4
Deciduous Orchards (w/o cover)	3/1	5/30	March	1.23	.75	0	0
			April	3.02	1.14	1.60	2.3
			May	5.82	1.83	3.99	5.7
			Season Totals	10.06	3.72	5.59	8.0
	3/1	6/30	March	.98	.60	0	0
			April	2.42	1.10	.94	1.3
			May	4.81	1.73	3.08	4.4
			June	6.46	2.32	4.15	5.9
			Season Totals	14.67	5.75	8.17	11.7
Strawberries	3/1	4/30	March	2.18	1.29	.14	.2
			April	3.88	1.20	2.68	3.8
			Season Totals	6.05	2.48	2.82	4.0
Watermelons	3/25	7/12	March	.24	.14	0	0
			April	2.25	1.09		
			May	4.53	1.70		
			June	5.26	2.17		
			July	2.07	.96		
			Season Totals	14.35	6.07		

1/ Use 0.14 inches per day after maturity through September.

Page

Figures

Tables

CHAPTER 5. IRRIGATION METHOD SELECTION

GENERAL

Selecting the irrigation system for a site is not always straighforward but is dependent upon many factors. Often times the case is that some sites are adaptable to several methods of irrigation with the final selection being based on factors such as initial cost, operating costs, adaptability to farming operation, adaptability for other uses and personal preference. Methods of irrigation used in South Carolina have advantages and disadvantages that are discussed in this chapter. This chapter will also discuss the various factors to consider in determining method suitability and provide general guidance in irrigation method selection.

METHODS OF APPLYING WATER

There are four basic methods of applying water: (1) sprinkler, (2) trickle, (3) subirrigation, and (4) surface.

SPRINKLER IRRIGATION

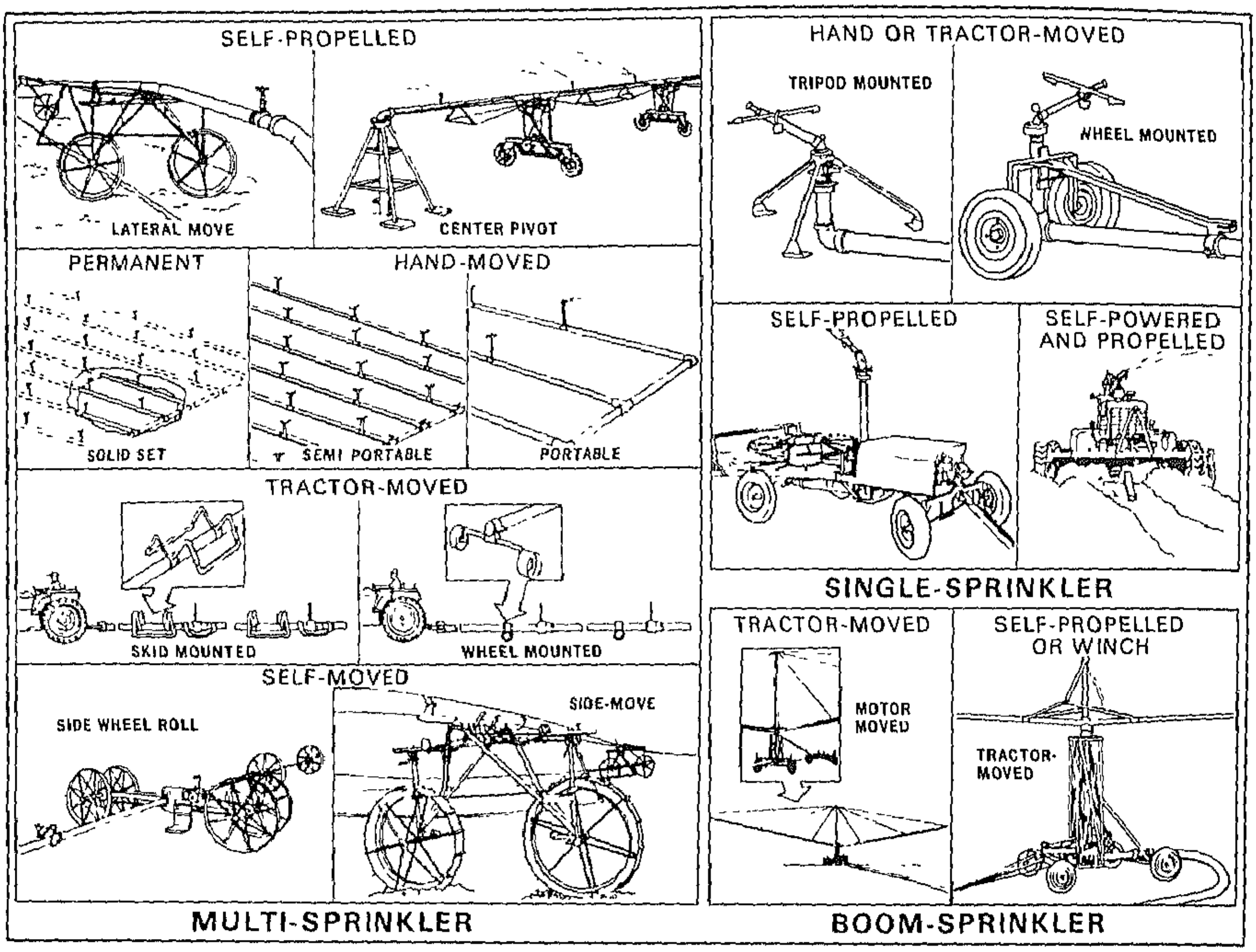
Sprinkler irrigation is a system in which the irrigation water is distributed to the field through pipelines and applied to the soil by spraying with sprinkler nozzles or perforations operated under pressure. Types of sprinkler systems include: permanent solid-set, hand move, tractor move, wheel or skid mounted, side move or side wheel-roll power move, hand or power moved single sprinkler (volume gun), power moved boom sprinkler and self propelled lateral move or center-pivot. The majority of sprinkler systems used in South Carolina are power moved volume gun (traveling gun) and center pivot. See Figure 5-1 showing the types of sprinkler irrigation systems.

TRICKLE IRRIGATION

Trickle irrigation is a system for efficient, slow application of water for irrigation directly to the crop root zone area. The water is applied on or below the soil surface through emitters or applicators placed along small diameter laterals operated under pressure. Common types of emitters include orifices, micro tubes, sprayers, porous or perforated tubing and bubblers. See Figure 5-2 showing typical emitters.

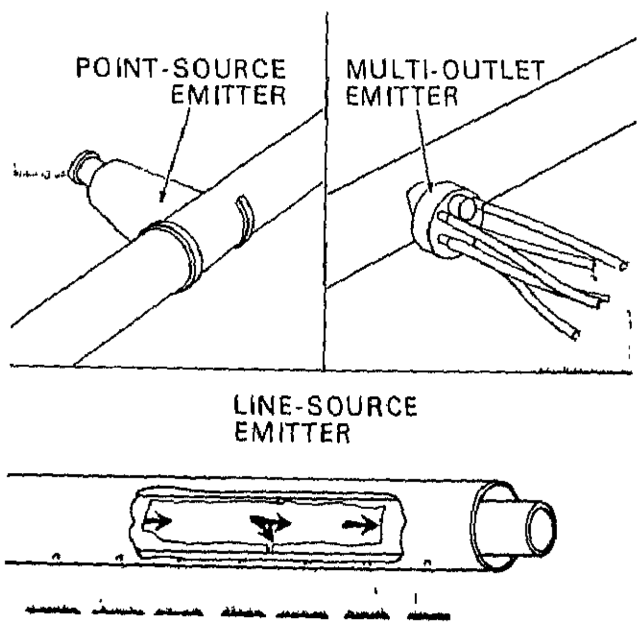
SUBIRRIGATION

Subirrigation is a system where the water is supplied to the root zone of the crop by controlling the water table (natural or artificial). The basic types of subirrigation are open ditch and under-ground conduit.



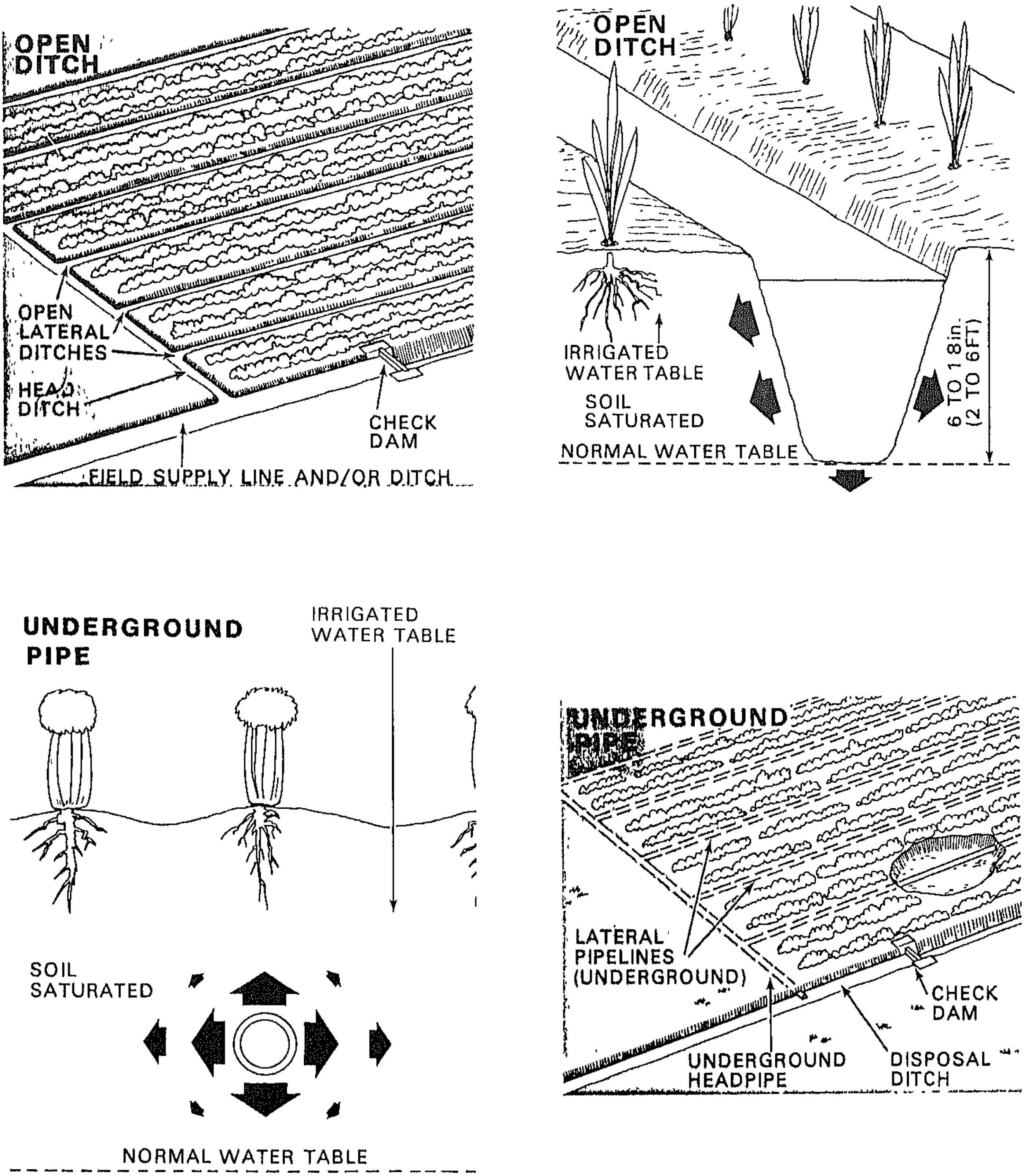
TYPICAL SPRINKLER IRRIGATION SYSTEMS

FIGURE 5-1



TYPICAL TRICKLE EMITTERS

FIGURE 5-2



TYPICAL SUBIRRIGATION SYSTEMS

FIGURE 5-3

The water table is usually controlled by the use of check dams. See Figure 5-3 showing typical subirrigation systems.

SURFACE IRRIGATION

Surface irrigation is a system where the irrigation water is distributed and applied by gravity flood flow over the area to be irrigated. Surface flood methods include furrow, level and graded border, contour levee and contour ditch. There are few if any true surface irrigation systems in South Carolina.

FACTORS AFFECTING THE IRRIGATION METHOD SELECTION

TOPOGRAPHY

If the topography of the land is level or can be made level without too much expense, then it will have little affect on the irrigation method. If the land is sloping, it may be limited to only the sprinkler or trickle irrigation system. With the sprinkler method, water can be applied slowly enough to prevent runoff and possible erosion. With the trickle irrigation systems, the emitter discharge rates can be matched to soil intake rates and uniform pressure distribution can be obtained through pressure regulation and lateral arrangement. Surface irrigation methods are applicable to level or nearly level land; however, very little, if any, surface irrigation is used in South Carolina.

WATER INTAKE RATE

The water intake rate of the soil affects the method of irrigation selected. The sprinkler and trickle irrigation systems can be used on low intake rates (0.5 inches per hour or less), or high intake rates (3.0 inches per hour or greater). The actual soil intake rate will dictate the type of sprinkler system used since some sprinkler systems have application rates higher than the soil intake rate. The intake rate for trickle irrigation systems will dictate the maximum application rate and number of emitters for a particular system. For subirrigation systems, the soil

WIND ACTION

Wind action can affect the water application efficiency of the sprinkler method. Strong winds will increase the direct evaporation losses to the atmosphere. These losses are greater as temperature and wind velocities increase and as humidity, drop size, and application rates decrease.

Table 5-1 summarizes the factors affecting the irrigation method selection.

Table 5-1. Factors Affecting the Selection of a Water-Application Method

Water Application Method	Factors Affecting Selection: Topography	Water Intake Rate of the Soil	Wind Action
Sprinkler	Adaptable to both level and sloping ground surfaces.	Some sprinkler systems limited by intake rate. However, any intake rate can be sprinkler irrigated.	Wind may affect application efficiency.
Trickle	Adaptable to all land slopes.	Adaptable to all intake rates.	No effect.
Subirrigation	Land should be level or contoured.	Adaptable to intake rates of 0.5"/hour or greater. Adaptable only to those soils which have an impervious layer below the root zone or a high controllable water table. Permeability should be 2 in/hr or greater for best results.	No effect.
Surface Irrigation	Adaptable to nearly level land where land leveling can be provided at a reasonable price and soil depth is sufficeint to not expose unproductive soil.	Soils with high intake rates are not suitable for surface irrigation.	Very little effect.

Once the method of water application has been selected (sprinkler, trickle, or subirrigation), it is desirable to select the specific type of system that is best suited to the farming operation, soil and crop requirements, and desires of the farmer.

PERMANENT/SOLID-SET

Description

A solid-set system is an aluminum pipe system that is placed in the field or fields to be irrigated prior to the start of the growing season and left in place throughout the growing season. A permanent solid-set system is defined as a pipe system placed underground with only a portion of the risers and sprinklers above ground. Almost all the permanent systems being installed today use pressure rated polyvinyl chloride (PVC) plastic pipe.

Permanent and solid-set systems are normally designed for spacings of 40 ft x 40 ft, 40 ft x 60 ft, and 60 ft x 60 ft. When these systems are used in orchards, the spacings may be somewhat different to conform to tree spacing. The actual spacings are based on a percent of the sprinkler wetted diameter that is compatible with the farming operation.

The sprinklers are either single or dual nozzle design with operating pressures usually in the range of 30 to 60 pounds per square inch and a wetted diameter up to about 125 feet.

Risers are located out of the way of equipment and constructed to a height compatible with the height of the crop to be irrigated. The risers, when permanent, are supported in concrete anchor blocks.

The field application efficiency used in design ranges from 70 percent for daytime operation to 80 percent for nightime operation.

Advantages and Disadvantages

The advantages of solid-set and permanent systems are that they can be adapted to irregularly shaped fields, low labor requirement, adaptable for frost and freeze protection, and chemigation. The disadvantages are high initial cost and moderate energy use.

TRAVELING GUN

ion

guns are of two general types and are referred to as cable-
lers and hose-pull travelers. The cable-tow traveler can be
l as a gun sprinkler mounted on a wheeled chassis to which a
onnected and the machine winds up a steel cable anchored at
end of the field. Power to propel the cable winch is supplied
iliary engine, water motor, water piston, or water turbine.
cases, the auxiliary engine may drive the unit directly or
hydraulic pump which drives a hydraulic motor to propel the

The hose for the cable-tow is a woven synthetic fabric tube covered inside and out by either rubber or polyvinyl chloride. Hoses are available in sizes from 2½-inch to 5-inch and in lengths from 330 feet to 1320 feet.

The hose-pull traveler is a system composed of a large hose reel mounted on a four wheel cart to which is attached a polyethylene hose that pulls a single gun sprinkler through the field and also supplies water to the sprinkler. The trailer mounted hose reel is stationary at the end of the field while irrigation is being applied. The hose reel is driven by a turbine, bellows, water piston, or auxiliary engine and as the reel turns the hose is wound around the reel.

Hoses for the hose-pull are available in sizes from 2-inch to 4½-inch inside diameter. Hose length will vary from 620 feet to 1250 feet. The hose is made of polyethylene with a wall thickness of 3/16 to 9/16-inch depending upon the diameter.

The sprinkler is a high capacity nozzle ranging from 50 to 1000 gpm. Normally, the sprinkler pressure will be 70 to 100 psi. To satisfactorily operate, a large capacity cable-tow traveler will require a minimum pump discharge pressure of 125 psi on reasonably flat terrian to as much as 180 psi on steep terrain. In comparison a similar hose-pull system will require a minimum pump discharge pressure of 145 psi on reasonably flat terrain to as much as 200 psi on steep terrain.

The field application efficiency used in design is 70 percent. Under certain conditions higher efficiencies can be obtained.

Operation of Cable-Tow and Hose-Pull Systems

Cable-Tow Systems

To obtain maximum performance from the traveler, the system should be laid out to irrigate in the most economical manner. With a 660-foot hose a field up to 1400 feet long can be irrigated with the supply line across the middle of the field. The machine is moved into position in the first alley 60 to 120 feet from the edge of the field depending upon the size sprinkler. This will adequately water the outside edge and some water will be thrown out of the field. The cable will be uncoiled with a tractor and attached to an anchor which may be an earth anchor, tractor, truck or tree. The operator should be sure the anchor will withstand the pull exerted by the machine. The pull will depend upon the size of the machine. For a 4½-inch, 660 foot hose this could be more than 6000 pounds. The hose is unrolled and connected to a hydrant. There should be about 30 feet of hose behind the machine.

The machine will be positioned some 60 to 120 feet from the end of the field. The pump should be started and the sprinkler operated for about 30-45 minutes before the machine is placed in gear. Speed should be set to give the correct application of water. The anchor on the far end should be some 60 to 120 feet from the end of the field. When the

machine reaches the end it will stop traveling, but the sprinkler will continue to operate until the pump is shut down. A run time of 30 to 45 minutes on the end should adequately water the end. Figure 5-4 shows a typical layout for the cable-tow traveler.

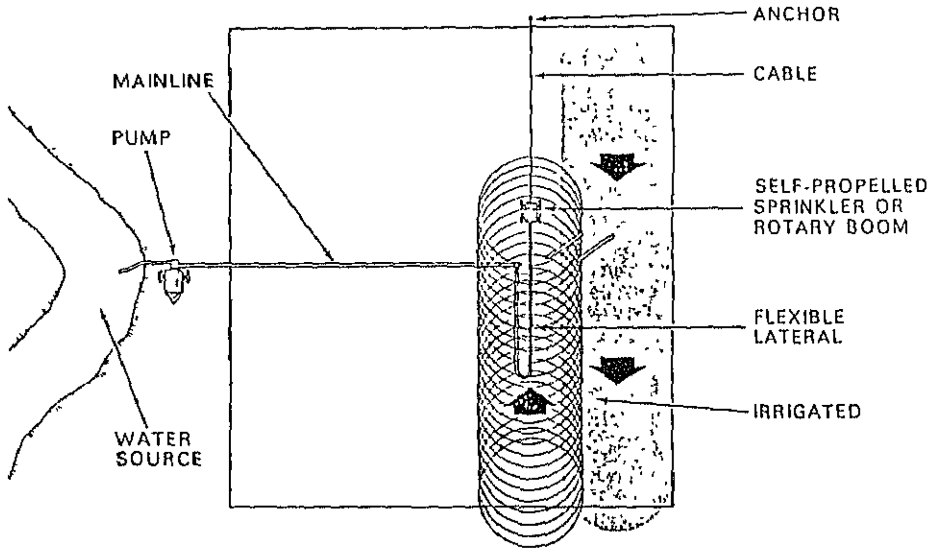


Figure 5-4. Layout for a traveling sprinkling system.

The normal spacing between alleys is approximately 70 percent of the sprinkler wetted diameter. Spacing will need to be reduced as wind speed increases.

When irrigation from an alley is completed, disconnect the hose from the hydrant, purge the hose of water, reel the hose onto the reel, and move the traveler to the next alley. Repeat the process of laying the cable and anchoring it and laying out the hose and connecting to the supply line. Once the pump is shut down, it will require from 45 to 60 minutes of time to move and set up the equipment for the next irrigation. A tractor will be needed to move the machine.

There are several items that should be considered in the maintenance of cable-tow systems. All of the pull of the traveler is against the cable. Check occasionally for frayed or worn cable and replace or repair before a break occurs. Check the hose for small cuts or nicks and repair before major damage occurs. The hoses can be repaired either with a metal hose mender or with a repair kit by a commercial company. When storing the hose, roll several coils of the hose loosely on the reel. This prevents stretching the end of the hose. Store hose away from grease, rodents, and sunlight. Do not try to reel the hose with water in it. Keep obstacles away from the hose. A hose that is handled carefully should last 10 years or more. Check the mechanical components of the machine. This includes the drive mechanism, sprinkler and hose reel. When the machine is operating, check the travel speed to ensure that it is operating at the desired speed and that it maintains the speed. Check the speed near the

beginning, middle and near the end of the run. Use the travel tables furnished by the manufacturer to set the speed to give the desired application, but check to see if the machine is performing as specified.

The cable-tow traveler is a versatile machine that can be used to apply animal wastes. The water drive units will be less satisfactory than some of the engine drive units. On the water drive units (water piston, water turbine and water motor) solids may tend to clog the drive mechanism. Check with a dealer on recommendations on using the machine for land application of wastewater. Generally, swine wastewater from a lagoon can be satisfactorily handled with any machine; swine pit wastewater, poultry, beef and dairy waste will have enough large and fibrous solids to possibly cause problems on some machines.

Hose-Pull Systems

The hose-pull traveler is fairly easy to operate. On low growing crops that a tractor can straddle, an alley is not needed. A tractor or other prime mover is used to unwind the hose and move the sprinkler cart and hose from the hose reel to the far end of the field. Depending upon the size of the sprinkler, the first alley will be 90 to 125 feet from the edge of the field. Some water will be wasted outside the field, but it is necessary to do this to adequately irrigate the edge of the field. It should be allowed to operate for 30 to 45 minutes before the hose reel is placed in gear. The sprinkler cart is then pulled through the field at speed to give the correct application of water. The sprinkler may be stopped 90 to 120 feet from the near end of the field and allowed to operate for 30 to 45 minutes to irrigate that end. The sprinkler may be operated in a full or part circle mode. Some growers will leave a pie-shaped section in front of the sprinkler unirrigated so that the sprinkler cart is operating on dry ground.

The hose and sprinkler cart travels best in a straight line, but due to the thick wall and heavy weight of the hose when it is full of water, it will follow some contour. Ridges will also aid in allowing the hose to follow a contour. Experience with operation of the machine will dictate the amount of contour that can be handled.

Spacing of alleys or travel lanes through the field will depend upon the particular sprinkler being used, i.e., diameter of coverage. Normal distance between travel lanes is 70 percent of the sprinkler wetted diameter. With prevailing winds, this may need to be adjusted. With different machines available, lane spacing will probably be from 220 to 330 feet.

Moving the hose-pull traveler is relatively easy. Once the sprinkler cart has reached the end of a row, the pump is shut down, the supply line is disconnected, and the hose reel is moved to the next lane with a tractor. Then the supply line is reconnected, and the sprinkler cart is moved to the far end of the next lane. The pump is then restarted. One man should be able to make the move in 30 to 45 minutes. All of the hose-pull travelers use stabilizers on the hose reel.

These are dropped to the ground when the machine is operating so that the hose reel will not tip over. On some of the machines, the hose reel is mounted on a turntable. With these models, an area on both sides of a center alley or road can be irrigated without moving the reel. With other machines, it will be necessary to turn the machine 180° to irrigate on both sides of a center alley.

Comparison of Cable-Tow and Hose-Pull Systems

In comparing the cable-tow traveler to the hose-pull traveler, one comes to the following conclusions:

1. The hose-pull traveler can be moved in a shorter length of time because there is no hose to reel in and no cable to unwind.

2. The hose-pull traveler will require more pressure to operate at comparable gallonage because the friction loss through the hose and drive mechanism is usually greater.

3. The initial cost of the hose-pull traveler will usually be greater than the cable-tow traveler.

4. Speed control, that is, uniform speed throughout the run may be more difficult to obtain with the hose-pull traveler. However, this will depend on the drive mechanism and the adjustment by the individual operator. Several companies now offer a speed compensation device as standard equipment or as an optional feature.

5. The hose-pull machines with auxiliary engine drive are being used for land application of wastewater. On these machines, only the sprinkler cart is subjected to the wastewater, whereas on the cable-tow traveler the entire machine is subjected to the waste water.

6. On the hose-pull traveler, only the amount of hose that is needed must be wound off the reel, whereas on the cable-tow traveler all the hose must be wound off the reel and the hose stretched out to allow water to flow through the hose.

7. The hose-pull traveler does not require a separate anchor; the cable-tow traveler requires an anchor, such as a tree, tractor, or h anchor to which the cable is attached.

hose on the hose-pull machine is pulled in a relatively straight n the cable-tow machine, the hose is pulled in a loop. In th obstructions, this could result in more hose damage on e-tow machine.

l lane is not required for the hose to travel for the hose-chine. Except in low growing crops, a travel lane is d for the cable-tow machine.

10. With the hose-pull machine, it is not necessary to walk to the middle of the field to connect or disconnect the hose to the supply line as is necessary with the cable-tow machine.

Advantages and Disadvantages of Travelers

The advantages of travelers are: (1) adaptable to many field sizes and shapes, (2) adaptable to topography from level to rolling, and (3) can be moved easily to irrigate several fields. The disadvantages of travelers are (1) they require alleyways for row crops, (2) water distribution is seriously affected by wind, (3) high application rates, and (4) high energy requirements for operation.

CENTER PIVOT

Description

A center pivot system consists of a single sprinkler lateral with one end anchored to a fixed pivot structure and the other end continuously moving around the pivot while applying water. The water is supplied from the source to the lateral through the pivot. The lateral pipe with sprinklers is supported on drive units and suspended by cables or by trusses between the drive units. The drive units are mounted on wheels, tracks or skids that are located 80 to 250 feet apart along the length of the lateral pipe, which may vary from 200 to 2600 feet.

Each drive unit has a power device mounted on it that drives the wheels, tracks, or skids on which the unit moves. The rate at which the drive unit and lateral pipe advance around the pivot is determined by the speed of the outermost drive unit. Alignment devices detect any drive units that become misaligned. Either the units are speeded up or slowed, as needed. Thus, the advance by the outermost drive unit sets off a chain reaction of advances, beginning with the second drive unit from the outer end and progressing along the lateral to the pivot. Should the alignment system fail and any drive unit become too far out of alignment, a safety device stops the whole system automatically before the lateral can be damaged.

There are four methods of powering a center pivot sprinkler system: hydraulic water drive, which utilizes pistons, rotary sprinklers, or turbines; electric motor drive; hydraulic oil drive, using pistons, rotary motors, or piston-cables; and air-pressure piston drive.

Hydraulic water-driven center pivot systems are powered by water from the sprinkler lateral pipe with pressures from about 60 to 120 psi at the pivot. Water used to drive the systems is discharged to the field. On the piston-drive systems, each piston-drive unit activates a set of

trojan bars. The trojan bars engage wheel lugs to turn the drive unit wheels. The rotary sprinkler and turbine drive systems transmit power to the wheels of each drive unit through a gear box. Other systems use a chain and sprocket mechanism connecting the gear box and the drive wheels.

The electric-drive center pivot systems have motors of 1/2, 3/4, 1 or 1½ hp mounted on each drive unit. Most systems operate with 440-volt or 480-volt, 3-phase 60-cycle electric power. Electric power is supplied by an engine-driven generator located at the pivot, or through underground cables which convey electric power to wiring on the moving lateral.

In oil-powered systems, the soil-supply and return-flow pipelines extend from the oil pressure pump and oil reservoir to the piston or rotary motors located on each drive unit. The oil pump is powered by an electric motor or internal combustion engine and maintains 600 to 2000 psi oil pressure in the oil lines.

The cable-drive system has one oil-pressure powered hydraulic cylinder at the pivot point. As the cylinder reciprocates, propelling power is transmitted to each drive unit through a steel cable that extends from the hydraulic piston to the outer drive unit.

Water is applied to the soil along a center pivot lateral at a low rate near the pivot to progressively higher rates toward the outer end. The application rate varies along the lateral because the length of time water is applied to the field decreases from the pivot to the outer end due to the increasing travel speed of the lateral.

The type of sprinklers, their spacing along the lateral, and the diameter of area covered from an individual sprinkler affect the application rates along a center-pivot lateral. There are three common variations in sprinkler types and arrangements along the lateral, all of which can produce uniform water distribution.

The small to large sprinkler arrangement uses some of the smallest agricultural sprinklers near the pivot, gradually increasing sprinkler size to large sprinklers at the outer end of the lateral, with 35 to 40 sprinklers used on a 1300 ft. lateral. Recommended pivot operating pressure using this nozzling concept varies from 60 to 100 psi.

There is a sprinkler arrangement using the same medium-sized sprinklers with variations in nozzle size and sprinkler spacing along the lateral. The widest spacing of sprinklers is near the pivot and the closest spacing at the outer end of the lateral. These laterals have 80 to 100 sprinklers normally operated with a pivot pressure of 45 to 75 psi.

The third sprinkler arrangement has fixed sprinklers with spray-type nozzles. Low pivot pressures from 20 to 40 psi are suitable for spray nozzle operations.

The spray-type center pivot lateral has the smallest drops, but the highest peak application and the shortest duration of application. Rates vary from 6 to 12 in./hr at the end of a 1300 ft. lateral. The medium-sized sprinkler type lateral has the next highest application rates with a peak varying from 2 to 3 in./hr. The variable sized sprinkler-type lateral gives the largest drops, but the lowest peak application rates, from 1.0 to 1.5 in./hr.

The application rates are determined by the nozzle size, nozzle pressure, sprinkler spacing, length of lateral and sprinkler types used. Once these items are fixed by the manufacturer, the application rate for that point along the lateral is fixed and will not be changed by varying the speed of lateral rotation. Changing the lateral speed only changes the depth of water applied.

When water application rates exceed soil intake rates, surface runoff can occur. Runoff results in poor water distribution, lower water application efficiency, and potential erosion. This problem is inherent in the design of all center-pivot irrigation systems but is more serious with low-pressure systems due to the very high peak application rates associated with this design. Crop production practices can be managed to significantly reduce the runoff potential.

Advantages and Disadvantages

The advantages of a center pivot system are the low labor reqirement, its adaptability to circular or square blocks with an addition of an end gun, its suitability to chemigation. The disadvantages are that it requires a field with no obstructions, application rates are usually high, especially at the outer end of the pivot, resulting in excess runoff on low intake soils, and there is a tendancy for wheels to cut deep ruts in some soils. The center pivot system ranges in energy use from low to medium.

Table 5-2 lists the factors affecting the selection of sprinkler irrigation systems.

Table 5-2. Factors Affecting the Selection of Sprinkler Irrigation Systems

Type of System	Maximum Slope	Approximate System Water Application Rate Min.	Max.	Shape of Field	Field Surface Conditions	Maximum Height of Crop	Labor Required	Size of Single System	Approx. Initial Cost[1]	Average Operating Cost[2]	Adaptable to: Cooling & Frost Protection	Chemical Application	Fertilizer Application	Liquid Animal Waste Distribution
	%	in/hr		-	-	ft	man-hours/ac-in	acre	$/acre	$/ac-in	-	-	-	-
MULTI-SPRINKLER Permanent and Solid Set	No limit	.05	2	Any shape	No limit	No limit	0.04	1 or >	950-1200	3.00-3.50	Yes	Yes	Yes	Yes
Center Pivot High Pressure (80 psi @ pivot)	20	1	1.5	Circular, square or retangular	Clear of obstructions, path for towers	8-10	0.05	1.5-200	400-450	3.75-4.50	No	Yes	Yes	Yes
Medium Pressure (60 psi @ pivot)	20	2	3	Circular, square or retangular	Clear of obstructions, path for towers	8-10	0.05	1.5-200	350-400	3.00-3.50	No	Yes	Yes	Yes
Low Pressure (30 psi @ pivot)	20	6	12	Circular, square or retangular	Clear of obstructions, path for towers	8-10	0.05	1.5-200	300-350	2.00-2.50	No	Yes	Yes	Yes
SINGLE-SPRINKLER Manual Move	15	0.25	1.0	Any shape	Safe operation of tractor	No Limit	1.00	40-80	300-350	8.00-9.00	No	Yes	Yes	Yes
Self-Propelled Cable-tow	15	0.25	1.0	Rectangular	Lane for winch and hose	No Limit	0.25	40-100	300-350	6.00-6.50	No	Yes	Yes	Yes
Hose-drag	No limit	0.25	1.0	Rectangular	Lane for sprinkler cart	No Limit	0.10	40-100	400-450	6.00-6.50	No	Yes	Yes	Yes

1/ 1982 prices. Cost based on water supply existing (well, reservoir, etc.) at the field. Cost includes pump, power unit, and distribution system.

2/ 1982 prices. Includes fuel and labor cost only. Fuel cost based upon average factory data for fuel consumption by diesel powered systems in good repair. All systems' cost based on a pumping lift of 70 feet.

TRICKLE IRRIGATION

DESCRIPTION

Trickle irrigation is the efficient application of water to the soil at low rates, 0.5 to 50 gallons per hour (gph), through emitters operating at low pressures, 5 to 30 psi. Emitters may be orifices, porous tubing or perforated tubing and may be placed on or underground. The objective is to continuously supply each plant with enough moisture to meet evapotranspiration needs without excessive water loss, erosion, or damage to plants by poor water quality. This method of irrigation is suited to orchard and row crops, nurseries, greenhouse operations, and urban landscaping. Field application efficiency is the highest of any irrigation method. For design purposes, the application efficiency can be as high as 90 percent.

SYSTEM COMPONENTS

Figure 5-5 shows a typical trickle irrigation system. The various components are discussed below.

Emitters

The system and its performance are based on a specific discharge for each emitter at a design pressure. Therefore, companies providing emitters need to furnish performance curves that show gph flow rates vs. pressure for each size of emitter to be used. Permissible flow rate is usually ±10%[1] of the average flow rate, therefore, these performance curves are needed to determine the permissible pressure variation. See Figure 5-6 for a typical performance curve for a trickle emitter. Using Figure 5-6, the permissible variation in flow rate for a 1.0 gph flow rate is from 0.9 gph to 1.1 gph. The pressure corresponding to 0.9 gph and 1.1 gph is 12.5 psi and 17.3 psi. The maximum pressure loss between the first and last emitter would then be 4.8 psi (17.3 psi - 12.5 psi).

Emitters generally fall under two categories - those that apply water by the drip process at flow rates of ½ to 2 gph and those that apply water by

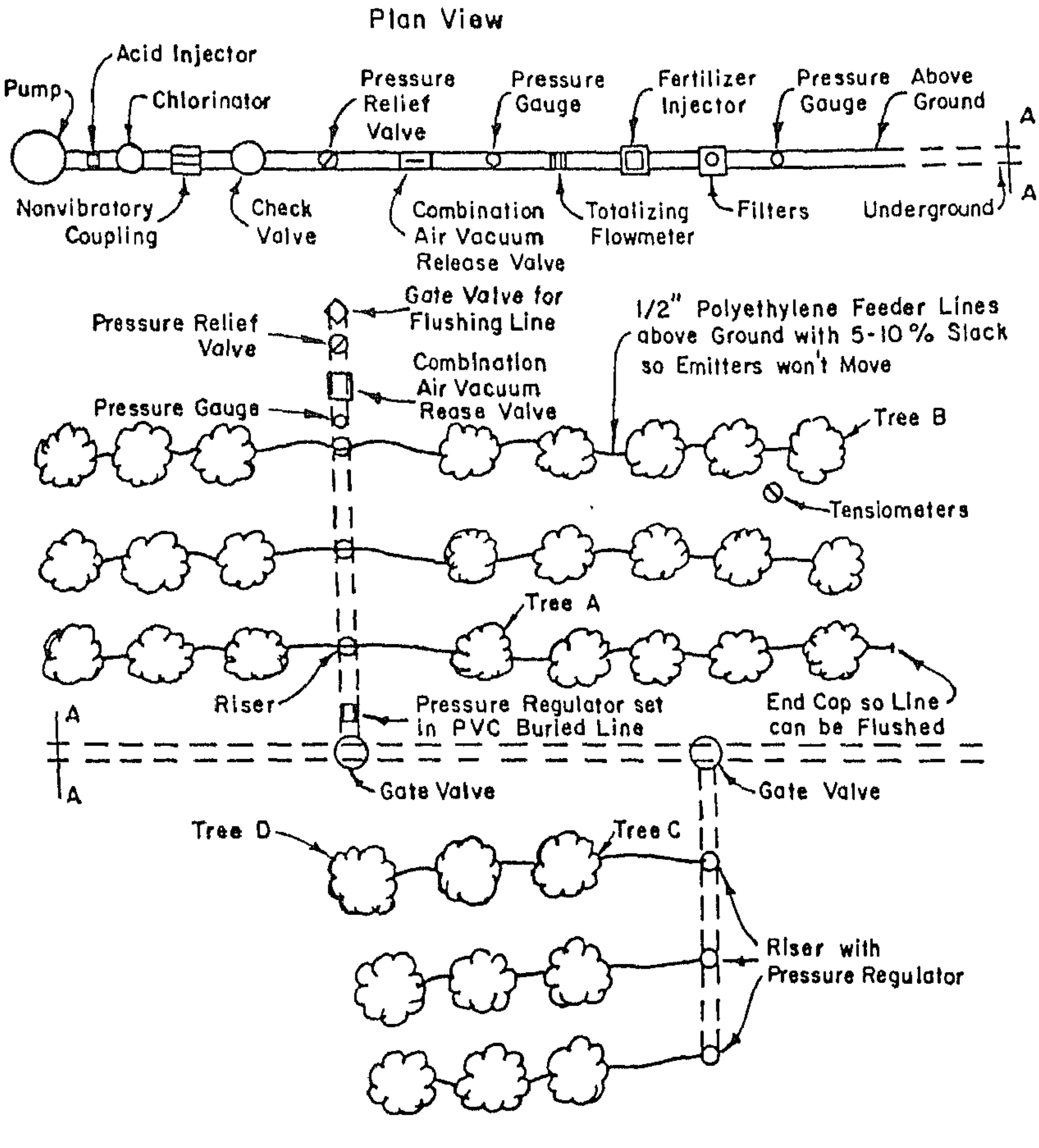


Figure 5-5. Typical Trickle Irrigation System

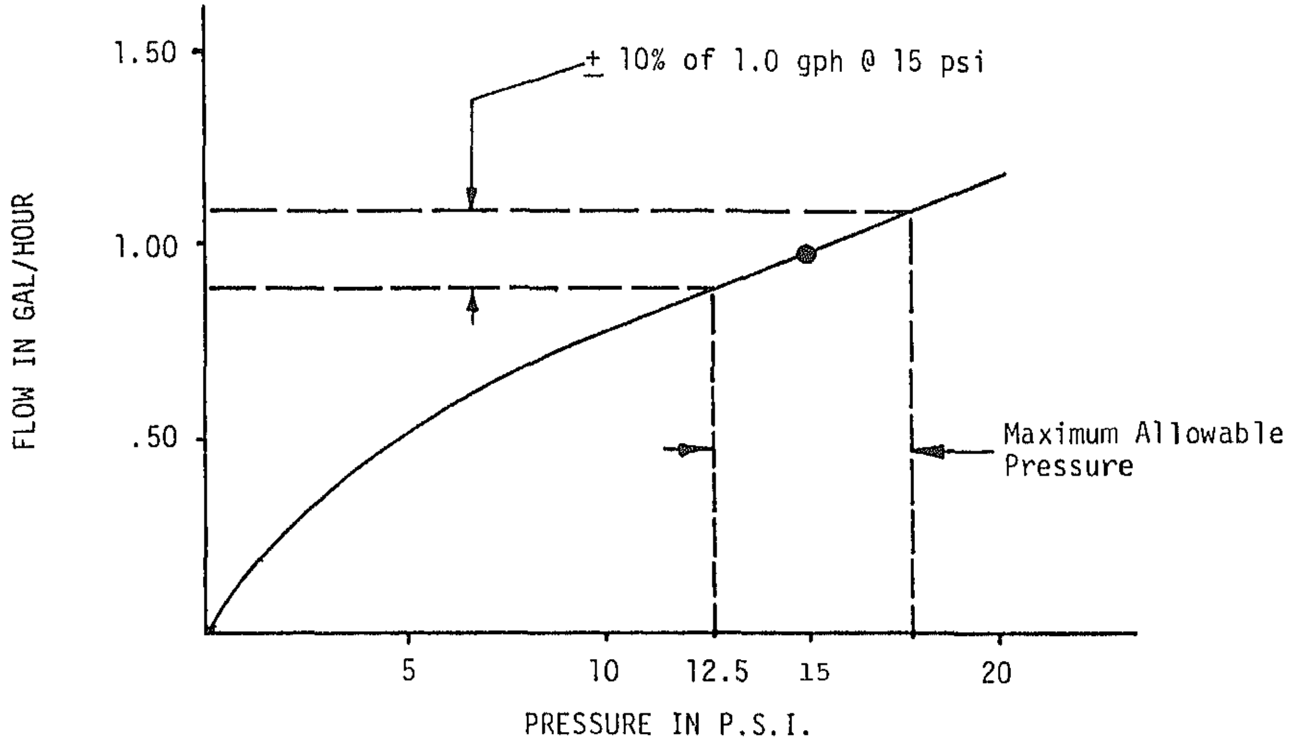


Figure 5-6. Typical Performance Curve for Trickle Emitter

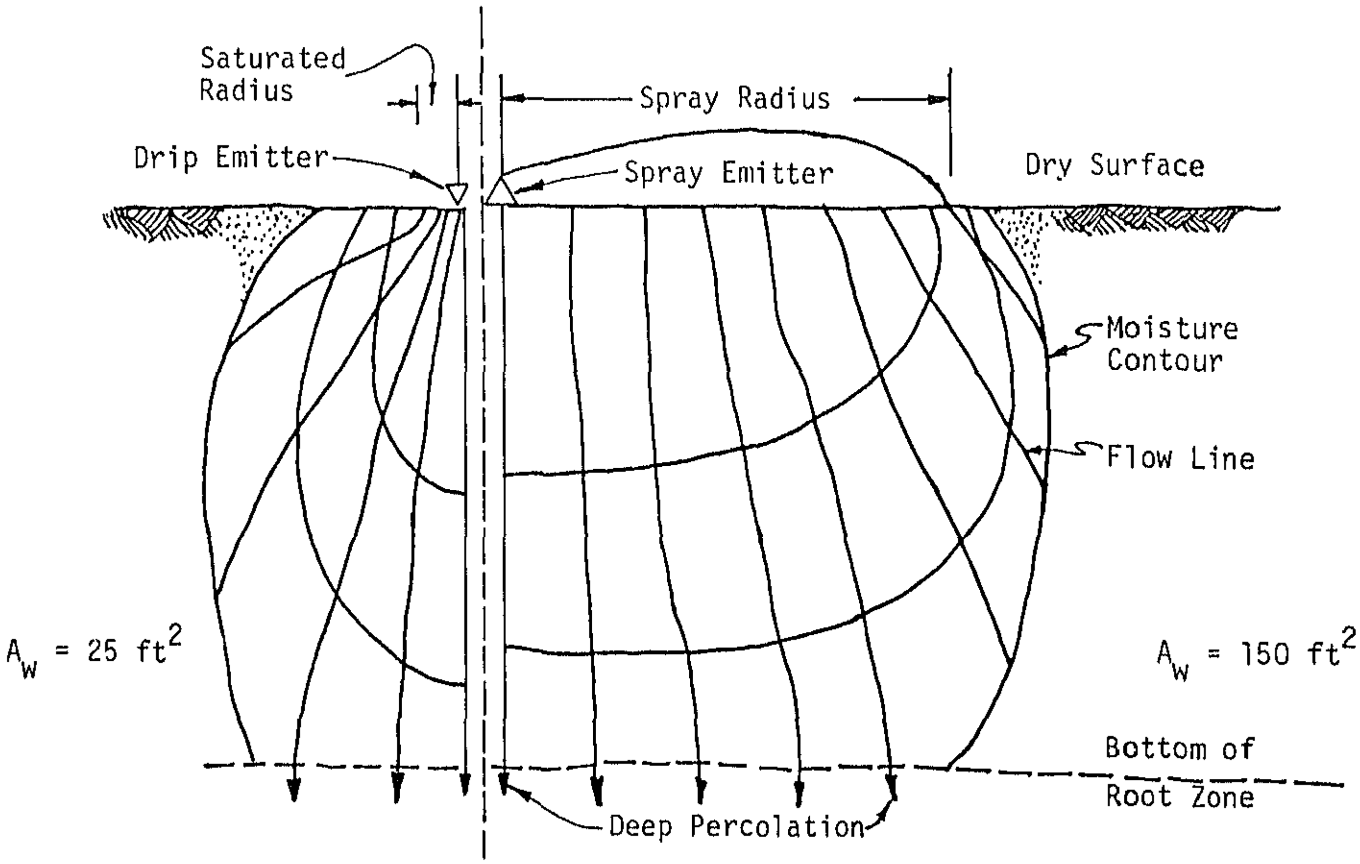


Figure 5-7. Comparison of idealized wetting patterns in a homogeneous fine sandy soil under a drip and a spray emitter.

Table 5-3. Estimated wetted areas for different soil textures, rooting or soil depths, and degrees of soil stratification from a 1.0 gph trickle emitter under normal field operation.

Soil or Root Depth and Soil Texture[1]	Degree of Soil Stratification[2]		
	Homogeneous	Stratified	Layered[3]
	Equivalent Wetted Soil Area[4]		
	$S_e \times S_w$ ft x ft	$S_e \times S_w$ ft x ft	$S_e \times S_w$ ft x ft
Depth 2.5 ft			
Coarse	1.2 x 1.5	2.0 x 2.5	2.8 x 3.5
Medium	2.4 x 3.0	3.2 x 4.0	4.0 x 5.0
Fine	2.8 x 3.5	4.0 x 5.0	4.8 x 6.0
Depth 5 ft			
Coarse	2.0 x 2.5	3.6 x 4.5	4.8 x 6.0
Medium	3.2 x 4.0	5.6 x 7.0	7.2 x 9.0
Fine	4.0 x 5.0	5.2 x 6.5	6.4 x 8.0

[1] Coarse includes coarse to medium sands, medium includes loamy sands to loams, fine includes sandy clay loam to clays (if clays are cracked, treat like coarse to medium soils).

[2] Most all soils are stratified or layered. Stratified refers to relatively uniform texture but with some particle orientation and/or some compaction layering which gives higher horizontal than vertical permeability. Layered refers to changes in texture with depth as well as particle orientation and moderate compaction.

[3] For soils with extreme layering and compaction which causes extensive stratification, the S_e and S_w may be as much as twice as large.

[4] The equivalent wetted rectangular area dimensions, S_e and S_w, are 0.8 times the wetted diameter and the wetted diameter, respectively.

Lateral Lines

Lateral lines normally are designed so that when operating at the design pressure, the discharge rate of any emitter served by the lateral will not exceed a variation of ± 10 percent of the design discharge rate. [SCS max. is ± 15 percent (Std. 441).]

Lateral lines supply water to the emitters. Polyethylene or similar material is used for the lateral lines. The most common sizes used are the ½ inch, 3/4 inch, 1 inch, and 1¼ inch. Normally, this material is installed above ground; therefore, it is important that it be purchased from a reputable dealer that recommends it for this use. Below ground installation should be considered where feasible. This will extend the life of the material and protect it from damage.

Slack is left in the lateral line so that temperature variations will not pull the emitters away from their initial position. When computing friction loss in lateral lines, it is important to use the correct tables for the inside diameter of pipe being installed. Inside diameters vary, depending on the manufacturer and materials used.

Lateral lines are connected to buried main lines and sub-main lines through risers, flexible PVC, or other acceptable means. Pressure regulators may be installed on each riser where extreme elevation variations exist, and the allowable pressure variation must be controlled in the lateral lines. Use of pressure regulators increases costs and maintenance and should not be installed where there is not a real need.

Lateral lines are capped on the outlet end by means of a screw cap or other device. This is removed periodically so the line can be flushed to remove sediment and other debris.

Main and Sub-main Lines

Main and sub-mains are permanent pipelines normally constructed of thermoplastic materials that deliver water to the lateral lines. They are buried below ground and installed in accordance with good engineer

Fertilizer Injectors

Fertilizer should be injected upstream of the filters so unfiltered fertilizer will not plug the lateral lines and emitters.

Chemical Injectors

Chlorinators are optional, depending on the quality of water used. Guidelines for application of liquid chlorine to inhibit iron and slime clogging should be obtained either from manufacturers, Appendix E of this Guide, or other reputable sources.

Tensiometers or Other Soil Moisture Checks

Tensiometers, neutron probes, and soil moisture locks have been used to check the soil moisture condition. Normally, a check is made at a depth where the main root concentration is found. A second soil moisture check is made below the main root zone. When water is reaching this area, the irrigation should be stopped. For tree crops, tensiometers could be placed at an 18" and 36" depth and about 15 to 16 inches from point of application of drip emitters.

Valves

Gate valves, check valves, air valves, pressure release valves, flush out valves, etc., are to be installed as needed.

Filters

A filtration system shall be provided at the system inlet. The type of filter needed depends on the emitter selected and the quality of the water supply. It is best to use the emitter manufacturer's recommendations in selecting a filtration system. Three types of filters are used and are sometimes used in combinations. For instance, a sand separator may be used in very dirty water backed up by a screen filter. Sometimes a screen filter is used downstream from a sand filter in case of failure of the sand filter. Pressure loss of 5 to 15 psi can be expected across the filters.

ators - sometimes used to remove sand partricles where excep-
..irty water suply is used. The operation of a sand separator is
rinciple of centrifugal matter as small as 74 microns (200
hat this material is heavier than water. This is a rela-
e filtration system.

2. Screen filters - 20 mesh to 200 mesh screens are used to remove sediment and other foreign material. The industry is in the process of making automatic cleaning devices available. The filters will remove sand, debris, organic material, some minerals, and some silt.

3. Sand filter - looks much like a swimming pool sand filter. Normal design provides 1 sq. ft. of filter area to 20 gpm system capacity. For dirty water, this may go to 1 sq. ft. to 15 gpm. Sand filters can be automated to operate when there is a 5 to 10 psi differential across the filter.

ADVANTAGES AND DISADVANTAGES

The advantages of trickle systems are:

1. Costs are lower since smaller pumps, motors, and pipelines are installed.

2. Water application is more efficient because irrigation water is applied directly to the soil. This results in lower water use and energy demands because of lower presssures. Low pumping rates make it possible to use shallow wells, ponds and canals as a water source.

3. Labor requirements are reduced when adequate filters and water treatment are used.

4. Damage to crops is reduced in areas of poor water quality.

5. Optimum moisture conditions can be maintained and drying cycles reduced.

6. In orchard crops, weed growth between rows is reduced since water is normally applied to the canopy area.

7. There is better scheduling of irrigation for more effective use of rainfall.

8. Smaller pumps and motors may use single phase electricity in areas where three phase electricity is not available.

9. These systems have the capability of applying fertilizers and other agents, hence reducing operations.

10. These systems may be used on sites with steep slopes and erosive soils where runoff and pollution are a problem.

11. Water conservation due to travel lanes and other spaces between plants that are not irrigated.

The disadvantages of trickle systems are:

1. Moisture distribution is limited in sandy soils req emitters per tree canopy.

2. Clogging can result from sand, organic growths, or cal precipitations.

3. Life expectancy of systems is low.

4. Salt build-up in soils may result in areas of poo

5. Requires a high degree of management skills.

Table 5-4 lists factors affecting the selection of tri systems.

Table 5-4. Factors Affecting the Selection of Trickle Irrigation Systems

Type of System	Maximum Slope	Maximum Water Intake Rate Soils	Shape of Field	Adaptable to: Orchard & Vineyards	Adaptable to: Row Crops (row or bedded)	Adaptable to: Sown, Drilled or Sodded Crops	Labor Required	Approx. Initial Cost 1/	Average Oper. Cost 2/
	%	(in. per hr.)	-	-	-	-	man-hr / ac-inch	$/acre	$/ac-inch
Point-Source Emitters	No Limit	Any	Any Shape	Yes	No	No	0.15	600-800	2.25-2.50
Line-Source Emitters	No Limit	Any		No	Yes	No	0.15	600-800	2.25-2.50
Subsurface	5	1.5		No	Yes	Yes	0.15	600-800	2.25-2.50
Bubbler	5	3		Yes	No	No	0.15	600-800	2.25-2.50
Spray	No Limit	Any		Yes	No	No	0.15	600-800	2.25-2.50

1/ 1982 prices. Cost based on water supply existing (well, reservoir, etc.) at the field. Cost includes pump, power unit, and distribution system.

2/ 1982 prices. Includes fuel and labor cost only. Fuel cost based upon average factory data for fuel consumption by diesel powered systems in good repair. System costs are based on a pumping lift of 70 feet and an emitter pressure of 15 psi.

SUBIRRIGATION

GENERAL

Subirrigation involves the application of water on level to gently sloping slightly wet to wet soils to create an artificial or perched water table over some natural barrier that restricts deep percolation. Moisture reaches the plants through capillary movement. The basic principle of this method of irrigation is the control of the water table to supply moisture to plants from a subsurface zone saturated with free water.

Irrigation water can be introduced by either open ditches or underground conduits. The water table is maintained at some predetermined depth below the ground surface, usually 24 to 36 inches, depending on the rooting characteristics of the crop grown. The water table can be regulated by controlling the drainage scheme as it applies to subsurface water. Instead of removing subsurface water to make deeper rooting possible, drainage is curtailed and water is added to keep the water table high enough to provide adequate moisture to the root zone through capillary action within the soil. However, the drainage system is still responsible for removing excess surface water and maintaining control of subsurface water so that the water table does not remain in the root zone for a long enough period to cause crop damage.

The plan for drainage becomes more critical when the drainage facilities will be used for subirrigation. A planner must be assured of a number of items, as follows:

1. Ample water supply during dry season.

2. Naturally high water table, or a very slowly permeable soil layer below the root zone on which an artificially elevated water table can be maintained without excessive losses through deep percolation.

3. Rapidly permeable layer immediately below the topsoil that will allow comparatively free lateral movement of water.

4. Uniform and nearly level topography permitting complete and even distribution of water.

5. A well planned system of mains, laterals and structures which will permit orderly movement of water to all parts of the area.

6. Adequate outlet for drainage of the system.

SITE INVESTIGATION

It is important that the site be thoroughly investigated. Major items to be investigated are:

1. Soils. Normally, the soils used for subirrigation systems are classified as poorly drained or very poorly drained. The following soil characteristics are of major importance.

   a. Effective depth. The depth of soil material favorable for root growth should be at least 20 inches for most crops.

   b. Thickness of the first significant layer below topsoil. This may be the water-conducting layer. Thickness should be at least 12 inches. It should not exceed 36 inches where success of the irrigation system depends upon a very slowly permeable zone below.

   c. The hydraulic conductivity of the topsoil should be medium (5 in./hr) to high (20 in./hr), otherwise laterals will need to be closely spaced for good crop response.

   d. Natural wetness. Presence of a naturally high water table is indicated by wetness class. Should be slightly wet to very wet. Moderately wet is optimum.

   e. Permeability rate of first significant layer below topsoil should be at least 5 inches per hour if it is a major water conducting layer.

   f. Permeability of second significant layer below topsoil should not exceed 0.05 inch per hour. The importance of this layer depends largely upon depth. Ideally, artificial saturation of the soil should be based upon a naturally high water table and not upon a relatively impermeable layer, even though the natural water table itself may be "perched" in this manner. Since this layer is often only moderately deep, the permeability value may not provide key information.

   g. Underlying material. The nature of the material underlying the soil may be especially important. In communities underlain by porous limestone or marl cut by ditches and canals, maintaining a high water table may be difficult or impractical.

2. Topography. Normally, the land slope should not exceed one percent. When slopes are greater than one percent, the water table is difficult to build and maintain, the number of structures become excessive, and drainage water velocities may become erosive. Many times it is feasible to level the land prior to installing the system.

3. Drainage Outlet. The outlet must be investigated and must be evaluated as to its adequacy to provide the necessary drainage or steps taken to make it adequate. Many broad areas in the State do not have an adequate natural outlet. In such cases, the selected field area is ditched and diked around the perimeter to keep out water from other drainage areas. Pumps are then installed for drainage

outlet control. Water storage areas may have to be installed for the pumped system so that increased runoff will not cause offsite damages.

4. Water supply. There must be adequate water for irrigation. A supply rate of eight gallons per minute per acre is usually adequate for most crops.

ADVANTAGES AND DISADVANTAGES

The major disadvantage of some subirrigation systems is that generally more water may be used because of distribution losses and other inefficiencies. Estimated irrigation efficiency of these systems may be as low as 50 to 60 percent. With proper management, the irrigation efficiency could be increased significantly. Another disadvantage of the open ditch subirrigation system is the loss of crop land due to the ditches. The advantages of subirrigation systems are the low initial installation costs, low operating costs, utilization of ground water for crop production, and their capability for providing drainage where needed.

OPEN DITCH SYSTEM

Description

The open ditch system consists of water being supplied to the main supply ditch at the high point of the field. Irrigation water is conveyed by gravity through the entire field area with lateral ditches. Laterals are located to run from the main ditch on the contour or with less than about 1.0 foot vertical variation from end to end. Structures are used to restage the water at about 1.0 foot intervals or less so that water will back into the laterals and move laterally to raise the water table. See Figure 5-8.

Main ditches usually require control structures at or near 0.5 ft. vertical intervals, except on the steeper slopes where a structure is required at each lateral. The variation in depth to water table can then be controlled by one structure to stay within the 0.5 ft. permissible variation. A greater variation than this will usually result in part of the area being under-irrigated and part being too wet for shallow rooted crops.

Structures in ditches should be designed with removable gates so that designed drainage will not be impeded and the water levels still controlled for irrigation. A properly designed subirrigation system will prove to be equally valuable as a drainage system during the rainy season if properly managed.

Laterals should be on nearly flat gradients with a variation of not more than 0.5 ft. from end to end. The length of lateral to be supplied from one end should not be more than 1200 feet except in extreme cases. Laterals will, in most cases, be spaced from 60 to 200 feet, depending on the characteristics of the soil that govern the

lateral movement of water through it and the degree of water table management desired. Due to drainage requirements, a spacing greater than 200 feet is not desirable. With a spacing of 60 feet or less, 10 percent or more of the field may be in ditches, and thus spacing becomes critical.

Main and secondary distribution ditches will be designed (Manning's Formula) to carry necessary discharges. On a large system, dimensions of a channel in its lower reaches might be determined by requirements for drainage. Dikes for transporting water against grade to higher elevation for distribution should be designed according to sound and accepted principles.

Determining Water Table Levels

In order to know when to start irrigating and when to stop applying water, it is important to determine the depth to the water table below the ground surface. This determination can be made by using a simple gauge made from pipe 1½-inches in diameter and approximately 48 inches long, perforated with 1/8-inch holes. A gauge should be placed near the center of each 40 acres, spaced equidistant from laterals, and set upright in the ground with approximately 6 inches above the ground surface. The desired depth to the water table will vary with the crop stage and the rooting characteristics of the crop grown. Experience in the area will generally reveal the desired depth of the water table for the crop to be grown.

UNDERGROUND CONDUIT

DESCRIPTION

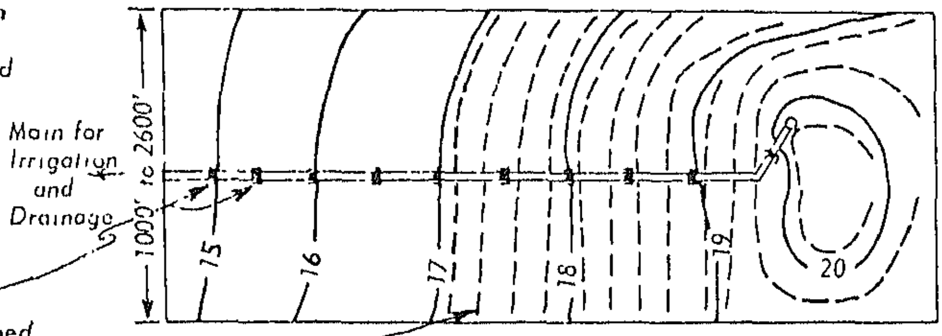
The function of underground conduits for irrigation is basically the same as the open ditch method. Lateral ditches are replaced by lateral pipelines which are usually perforated corrugated plastic tubing (drain tubing). Water is supplied through the drain tubing - regulating the water table. The water table is usually held just below the root zone where capillary movement of water due to tractive force of soil particles draw water up into the root zone.

As in the open ditch method of subirrigation, structures are needed to control the water table at its desired elevation. Structures, whether in an open ditch main or in a conduit main line, are designed to be adjustable so water can be released during excessive rainfall and water can be contained at the desired elevation during irrigation pumping. See Figure 5-8.

ADVANTAGES AND DISADVANTAGES

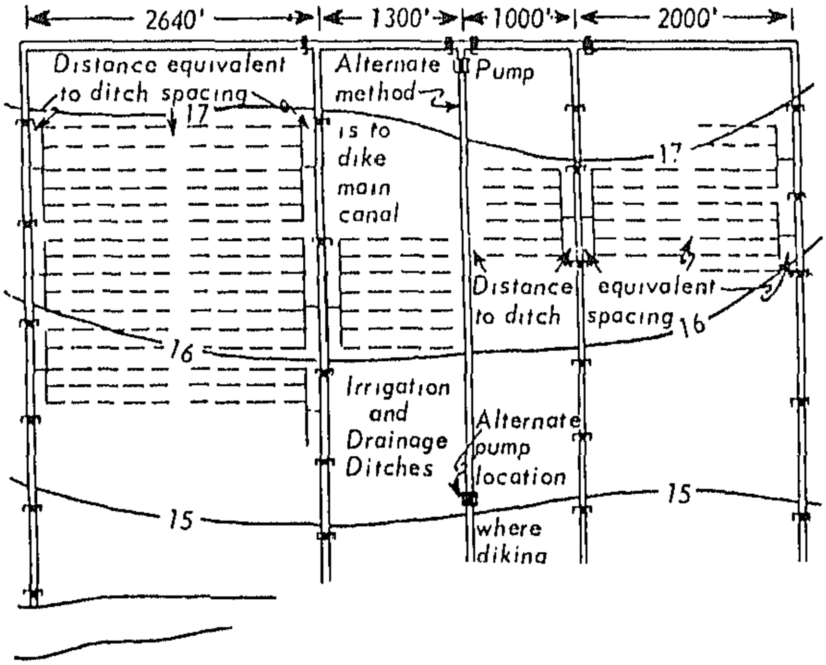
The advantages of the underground conduit are that it does not take up surface area, can be installed closer and deeper than ditches, low maintenance, and not influenced by cropping pattern. The disadvantages are higher initial cost than open ditches, requires mesh filter in sandy soils and may require special design in soils high in soluble iron. For more information on filter requirements for various soils, refer to the South Carolina Drainage Guide.

Small irrigation system with well at high point. Entire system acts as drainage and irrigation system.



NOTE:
1. Water is controlled at .5' interval.
2. Field laterals are stopped a distance from edge of field equal to half the lateral spacings.

Large Irrigation System. Water supply is pumped from deep ditch that connects with river. Where soil permits, an alternate system is to locate pump near river and dike central supply ditch to the high ground distribution point.



LEGEND

- --- Lateral
- Water Control Structure
- Pump
- 15 Contour Line
- o Well

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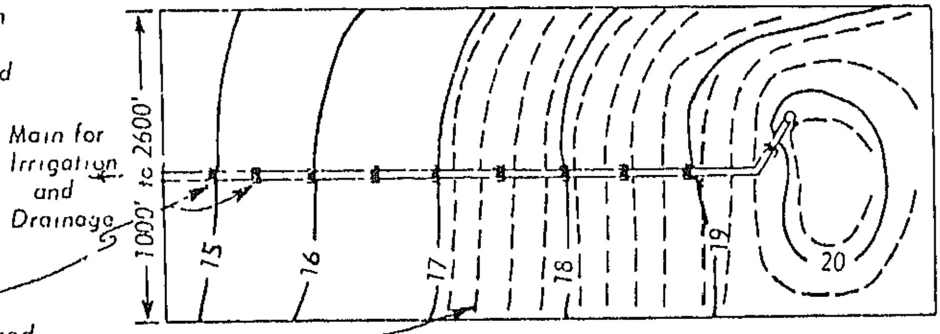

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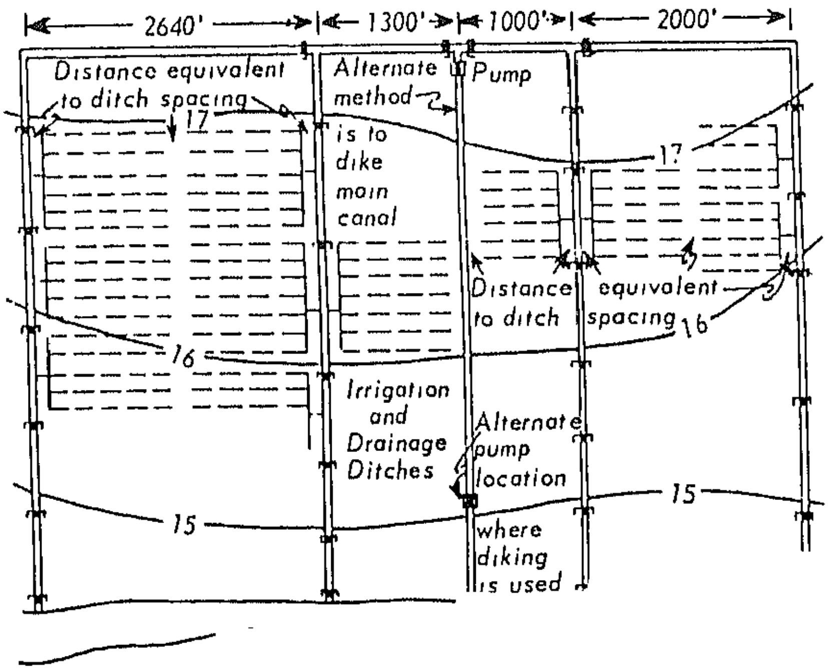


LEGEND

--- Lateral

Water Control Structure

Pump

15 Contour Line

o Well

NOTE:
In each of the above illustrations, th
of the edges of the irrigated field anc
at least one-half the lateral spacing.
area with heavy equipment without cr

Figure 5-8. Typical Subirrig

CHEMIGATION

Chemigation can be defined as the application of a chemical (fertilizer, herbicide, insecticide, fungicide, nematicide, etc.) via an irrigation system by injecting the chemical into water flowing through the system. Although the term chemigation is relatively new, the concept of applying fertilizer in the form of animal manures in the irrigation water likely began soon after the use of irrigation. Advances in irrigation systems and injection equipment design have stimulated research which has resulted in the chemigation application of herbicides (herbigation), fungicides (fungigation), nematicides (nemagation), and insecticides (insectigation). Chemigation is used for both soil and foliar applied chemicals; however, several factors should be considered before attempting to use chemigation as a means of applying chemicals.

Application of chemicals by chemigation occurs only where the irrigation water is applied; therefore, surface and trickle/drip type irrigation systems have only been successful for soil applied chemicals. Application of both soil and foliar applied chemicals have been successful with sprinkler irrigation systems.

Uniformity of chemical distribution is an essential element of successful chemigation and is proportional to the uniformity of water distribution by the irrigation system. The uniformity of application of water or chemicals by an irrigation system or sprayer is often expressed as the coefficient of uniformity (CU). The CU of properly calibrated ground based sprayers ranges from 50 to 92%, while aircraft normally obtain a CU of about 70%. Most types of sprinkler irrigation systems can be designed and operated to achieve CU's of 85% or greater; however, many solid set and portable pipe systems achieve CU factors of only 70-75%. Traveling gun type systems normally achieve a CU of 80% or less under optimum conditions, and most farmers achieve CU's of less than 70%. A continuously moving lateral system, such as a center pivot, normally achieves a CU of 90% when properly nozzled and operated. As with aircraft or ground based sprayers, the CU's of sprinkler irrigation systems decrease with increased wind velocity. Competent management is necessary to fully utilize the capabilities of chemigation.

The high CU's of center pivot and linear move systems make them ideally suited for total chemigation. The operator must determine whether the lower uniformity of other types of sprinkler irrigation systems is acceptable for chemigation. The minimum level of acceptable uniformity will vary, depending on the chemical applied. A lower CU value will be acceptable with chemicals which have a greater range of effective application rates.

When chemicals are injected into irrigation systems, there is a possibility of contamination of the water supply if the injection system is not carefully designed and maintained. The irrigator is responsible for installing an appropriate anti-syphon device to protect the water supply. See Chapter 6 for discussion on safety components necessary for chemigation.

Application of Fertilizers

Applying fertilizer through chemigation permits nutrients to be applied to the crop as they are needed. Several applications can be made during the growing season with little if any additional cost of application. Nitrogen, especially, can be applied during periods when the crop has a heavy demand for both nitrogen and water. Corn, for example, uses nitrogen and water most rapidly during the three weeks before tasseling. About 60% of the nitrogen needs of corn must be met by silking time. Generally, it is recommended that nearly all the nitrogen for the crop should be applied by the time it is pollinating, even though appreciable uptake occurs after this time. Fertilization through irrigation can be a convenient and timely method of supplying part of the plant nutrient needs. Nitrogen is ideally suited to chemigation and is the element most often applied to corn by this method. The ideal fertilization program would be one that provides nitrogen and moisture to plant roots as they are needed so there is never a deficiency or an appreciable surplus.

The fertilizer solutions most commonly used with irrigation applications contain both the ammonium and nitrate forms of nitrogen and have 28 to 32 percent nitrogen. Considerably more care is required if anhydrous ammonia is used. Because the per-unit cost for ammonia has been less than for solution forms of nitrogen, producers have shown an interest in applying ammonia in sprinkler water. Also, relative to solution forms of nitrogen, ammonia offers advantages in terms of economics and energy requirements for production and transportation.

Application of ammonia in sprinkler water, though attractive in terms of fertilizer costs, presents definite potential hazards unless special precautions are taken. Nitrogen can be lost to the atmosphere as ammonia gas and precipitation deposits can form which reduce the carrying capacity of irrigation pipes and may clog sprinklers.

A potential solution to precipitation and ammonia volatilization problems is acidification (adding sulfuric acid) of irrigation water prior to injection of ammonia. In the past, application of sulfuric acid with ammonia in water has not been economically feasible. If the price of sulfuric acid comes down, this approach may have real value. Ammonia use would become feasible. Although the ammonia form will be held a little more tightly in the soil than the nitrate form, the ammonium form will be rapidly changed to nitrate when the moisture, temperature, and aeration conditions in soils favor root growth. The fertilizer solution is injected into the irrigation delivery pipe--usually near the water pump. Safety devices must be installed to prevent the nitrogen solution from moving back into the water source if there is an interruption in pumping.

Almost any fraction of the total nitrogen application can be made successfully by chemigation. It is suggested that, under most conditions, not more than about one-third of the total intended nitrogen be applied in this manner.

Single applications of 20 to 30 pounds of actual nitrogen per acre are the most practical. There is probably little reason to apply nitrogen after silking, unless there are still symptoms of a deficiency of this element.

Although some phosphorus and potassium fertilizers may be applied by chemigation, they probably are applied more satisfactorily ahead of planting. Then, they are available to the crop as soon as root exploration of the soil begins. Phosphorus, especially, does not move down through the soil readily so, therefore, does not become available for benefitting early growth. On sandy soils where the need for potash may be high, it might be applied with nitrogen to coincide with the rapidly increasing amount needed for the period of rapid vegetative development. Where both potash and nitrogen may be needed later in the growth of a crop, it would be possible to add a liquid mixed fertilizer such as a 7-0-7 or similar grade. Adjustments would simply have to be made with the injection pump to ensure that an adequate amount of nutrient is applied.

Some phosphorus-containing fertilizers are corrosive, especially to brass or copper fittings. Some phosphate materials do not have sufficient solubility to be used satisfactorily in chemigation. If the irrigation water contains appreciable amounts of calcium, calcium phosphate may precipitate and clog nozzles, or screens, or both. Some solutions may also cause leaf burning if applied in too great a concentration.

Sulfur may become deficient on some sandy soils. This nutrient could be added by irrigation using nitrogen solutions containing sulfur. Several major nitrogren and 2 to 5 percent sulfur. Probably this should be done if there has been no other sulfur applied earlier in the year with conventional mixed fertilizer.

Micronutrients can be applied through irrigation systems. If a deficiency is positively identified in a growing crop, this may be the most satisfactory method of correction for that crop. However, the best ways to correct such deficiencies for successive crops probably are to apply micronutrient materials to the soil before planting or to the plants by foliar application as soon as the deficiency is recognized. Foliar applications of micro-nutrients seem to be most effective if they are not washed off the leaves by irrigation water or rain.

In order to capitalize on the convenience of applying nutrients, herbicides, or other agricultural chemicals through an overhead irrigation system, accurate amounts evenly distributed over the field must be accomplished. In the material which follows, equations are presented that will be useful in calculating the rate of material that must be added using either a center pivot or self-propelled gun traveler to apply selected sources of nitrogen. Application of other nutrients either as clear liquid mixed fertilizers, single nutrients, such as potash dissolved in water, or micronutrients dissolved in water,can also be applied using the same equation.

Fertilizer sources suitable for fertigation must be completely water soluble. Table 5-5 lists possible source of fertilizers for fertigation.

TABLE 5-5. COMMON SOURCES OF FERTILIZERS FOR USE WITH IRRIGATED SYSTEMS

Nutrient	Source
Nitrogen	Urea ammonia nitrate solutions are best. Soluble dry fertilizers can be dissolved under special circumstances. Aqua and anhydrous ammonia are not recommended due to problems with corrosion and volitilization.
Phosphorus	This is not recommended. Phosphorus is immobile in soils and is best applied with ground equipment. If used in irrigation systems, phosphorus compounds will have corrosion and precipation problems.
Potassium	Pure (white in color) source of potassium chloride is best. This is not commonly used because most potassium sources are not completely water soluble.
Sulfur	Sulfur-sulfate source is the best.
Micronutrients	Several sources are possible depending on crop needs. The Cooperative Extension Service offices maintain information on the suitability of the materials for use in irrigation systems.

Several cautions are needed when planning to apply fertilizer with irrigation water.

1. This is not foliar feeding. Soil application rates of nutrients should be based on current soil and plant testing.

2. Crops can be burned by improper application techniques.

3. Scheduling may be a problem during adverse weather conditions.

4. Nonuniform applications are a problem. Poor irrigation patterns are commonly on the ends of center pivot systems.

5. Fertilizers should be injected into the system with the firstwater flow. Fertilizers injected into a system already in operation may take considerable time to reach the perimeter.

6. This does not replace a basic fertility program. Lime, immobile nutrients, preplant or starter fertilizers still require conventional application practices.

Using Center Pivot to Apply Fertilizer

$$GPH = \frac{100\ AN}{P\ H\ W}$$

GPH = Liquid fertilizer to inject in gallons per hour

A = Total area actually irrigated in acres per revolution

N = Actual nitrogen (or other nutrients) to be applied, lbs/acre

H = Hours per revolution of system

P = Percent N (or other nutrients) in fertilizer

W = Weight of one gallon of liquid fertilizer, in lbs.

Example: 160-acre system, 80 hours/revolution, appy 50 lbs. of actual N, using 30 percent N liquid solution.

$$GPH = \frac{100 \times 160 \times 50}{30 \times 80 \times 10.65} = 31.3 \text{ gal/hr}$$

$$\text{or } \frac{31.3}{60} = .52 \text{ gal min}$$

Using Self-Propelled Gun Traveler to apply Fertilizer

$$GPH = \frac{100\ S\ L\ N}{43{,}560\ P\ W}$$

GPH = Liquid fertilizer to inject, gallons per hour

S = Rate of sprinkler travel, feet per hour

L = Distance between sprinkler lanes, feet

N = Actual nitrogen (or other nutrients) to be applied, lbs/acre

P = Percent N (or other nutrients) of liquid fertilizer

W = Weight of one gallon of liquid fertilizer in lbs.

Example: Travel speed of 90 feet/hour, 300 feet between lanes, 50 lbs. of actual N, using 30 percent liquid nitrogen fertilizer

$$GPH = \frac{100 \times 90 \times 300 \times 50}{43{,}560 \times 30 \times 10.65} = 9.7 \text{ gal/hr}$$

$$\text{or } \frac{9.7}{60} = .162 \text{ gal/min}$$

Application of Herbicides

tion of herbicides is advantageous from the standpoint that time . The effectiveness of some herbicides is increased by applica- ough irrigation water. Several herbicides are registered for o corn through the irrigation system. Eradicane, Sutan, azine, Lasso, and Lasso and Atrazine are currently be used in this manner. Tests at the University of hown that these herbicides have performed well when both water and electric drive center pivot systems. ts in Nebraska have shown that with some herbicides, the

rate may be reduced when application is made by the sprinkler water. It is very likely that certain other preplant and pre-emergence herbicides could be applied through a center pivot system with good results. A careful examination of the label will determine if the herbicide can be applied in irrigation water. The current Agricultural Chemical Handbook provides information on approved herbicides for South Carolina crops.

Generally, preplant and pre-emergence herbicides must be distributed in the surface two inches of soil to be effective against germinating weed seeds. As a rule of thumb, the herbicide should be applied with about 0.5 inch of water on sandy soils and 0.75 inch of water in fine textured soils. Large amounts of water may move highly soluble herbicides too deep, especially on sandy soils. Less water may not move certain herbicides deep enough.

To ensure good performance, apply the herbicide very soon after planting. Usually the field is tilled just prior to planting, but by the time the field is finally tilled and planted, it may take four to five days. It may take the sprinkler system one or two days to complete the application. Some weed seeds may have started to germinate before the herbicide is applied. It is important that the herbicide be applied within about five days of the final tillage operation. A good procedure is to till and plant one-half the circle, then start the system and herbigate while tilling and planting the rest of the circle.

Problems could arise if highly volatile herbicides such as Eradicare and Sutan are applied in the irrigation water to soils that are already wet. For best results, apply volatile herbicides to dry soil. Also, inject the herbicides all the time while irrigating or at the beginning of the set. Don't apply herbicides at the end of a set after the soil has been wetted. Where plenty of rainfall has occurred, the irrigator may be foreced to irrigate to apply the herbicide even though soil moisture is adequate if he has no other means of applying the chemical.

If at all possible, applying herbicides through a sprinkler system should be avoided when wind speeds exceed 10 mph. Strong winds can contribute to uneven application of water and herbicide. Also, drift

the area may become sterilized. If an overdose of herbicide is applied at any particular point, quite a large number of acres will be affected.

Application of Insecticides and Fungicides

Use of insecticides and fungicides through irrigation systems has been successful in research. No compounds are registered for use in South Carolina with irrigation systems as research continues to look for the best formulations and rates to use. Insecticides and fungicides that are effective in irrigation systems are foliar applied, requiring a low pressure injection pump. Foliar applied chemicals need small amounts of water during application. Application rates of 0.1" to 0.3" will allow good leaf coverage without washing the chemical off the leaf surface. High speed drive motors will allow application of low amounts of water. This should be planned before the system is installed to avoid unnecessary expense.

Waste Disposal

Disposing of waste on land is not a new concept. Crops have been grown for centuries on land used for spreading manure and sewage. These materials were regarded as fertilizers, not wastes. Many kinds of grasses, vegetables, legumes, and woody plants have been subjected to waste disposal. Grass seems to be the most effective vegetation for this purpose. Many species of grass possess a high water use factor combined with abundant root production. The roots and sod retard runoff and enhance infiltration. The plant leaves pump water back into the atmosphere. Wastes become pollutants when they are introduced into the air, water, or soil in excessive amounts or otherwise become offensive in the environment.

The interaction of soils, plants, and water must be thoroughly considered before a sprinkler disposal system is installed and expected to operate successfully.

Generally, an existing irrigation system can be utilized to apply effluent to the land. The sprinkler nozzle will need to be large enough to pass the solids that are in the effluent. One of the major

The total depth of effluent application per season can be determined when the total concentration of plant nutrients and/or metals is known. Technical Guide Standard 633 - Waste Utilization, provides guidance in this area.

Application rates must be selected to not exceed the intake rate of the soil. See Table 2-6 (Chapter 2) of this guide for guidance in determining maximum sprinkler application rates.

When effluent disposal is planned, especially on the heavier soils, extreme care must be exercised to plan drainage systems that will dispose of excess runoff without causing erosion or pollution. Examples of this might be to divert water from the disposal area through a grass buffer or filter zone before access to surface waterways is reached.

Some of the critical considerations of sprinkler application of effluent follow:

1. Excessive rate or volume of application may result in runoff and pollution of surface water.

2. Excessive application depths may result in pollution of ground water especially on highly permeable soils.

3. Effluent may contain toxic or detrimental materials to soil or plants.

4. Odors from sprinkling may be obnoxious.

5. Effluent is highly corrosive and may shorten the useful life of equipment.

6. Solids from the effluent may coat plant leaves and reduce photosynthesis.

The system should be operated with clear water for at least the last 15 minutes to wash the system as well as remove solids from the plants.

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 6. IRRIGATION SYSTEM COMPONENTS

Contents

Figures

Tables

CHAPTER 6. IRRIGATION SYSTEM COMPONENTS

GENERAL

In order to have an irrigation system operate as designed and function effectively, consideration of many irrigation components is necessary. This chapter will attempt to identify some of the components and briefly discuss them.

It is important to consider in the design, components that affect pressure losses and also those that affect control of operations. The characteristics and operation requirements of components may vary depending on the designs of different manufacturers. It is very important that the designer has the necessary data for all system components utilized in an irrigation system. This information needs to be secured from literature available from the manufacturer. Each designer should collect this information for all irrigation system components utilized in his area. Additional data on components is also available from technical manuals, publications on irrigation, and from National Engineering Handbook, Section 15 - Irrigation. Conveyance components for surface systems are discussed in NEH, Section 15.

The SCS Technical Guide provides minimum standards and specifications for many of the components to be discussed in this chapter.

PUMPING PLANT

SELECTION OF THE PUMPING PLANT

General

The pumping plant selected must be capable of delivering the required capacity at the designed operating pressure. Economy of operation is also a primary consideration. More detailed discussion of pumping plants is contained discussion of pumping plants is contained in Chapter 8 of the SCS National Engineering Handbook, Section 15 - Irrigation. It may be necessary to contact manufacturer's representatives to assure that the pumping plant selected can perform in accordance with the system requirements.

The function of an irrigation system pumping plant is to perform the work of moving water at the rate needed and at the pressure required to meet the requirements of the irrigation system. A pump operates best at the specific head and at the specific pump speed for which it was designed. The operating conditions should therefore be determined as accurately as possible. If there is a variation in operating head, both the maximum and the minimum should be determined and furnished to the manufacturer to permit selection of the most satisfactory pump. With the use of accurate data, the system planner can make proper selection of pumping equipment and assure the user a satisfactory performance of his system.

Pumps

Centrifugal, turbine, and propeller pumps are commonly used for irrigation pumping. Each type of pump is adapted to a certain set of conditions under which it will give efficient service.

Centrifugal Pumps

Centrifugal pumps are built in two types--the horizontal centrifugal and the vertical centrifugal. The horizontal type has a vertical impeller connected to a horizontal shaft. The vertical centrifugal pump has a horizontal impeller connected to a vertical shaft.

Both types of centrifugal pumps draw water into their impellers, so they must be set only a relatively few feet above the water surface. In this respect the vertical type has an advantage in that it can be lowered to the depth required to pump water and the vertical shaft extended to the surface where power is applied. The centrifugal pump is limited to pumping from reservoirs, lakes, streams, and shallow wells where the total suction lift is not more than approximately 20 feet.

The horizontal centrifugal (Figure 6-1) is the one most commonly used in irrigation. It costs less, is easier to install, and is more accessible for inspection and maintenance; however, it requires more space than the vertical type. To keep the suction lift within operating limits, the horizontal type can be installed in a pit, but it usually is not feasible to construct watertight pits more than about 10 to 15 feet deep. Electrically driven pumps are best for use in pits because they require the least cross-sectional area.

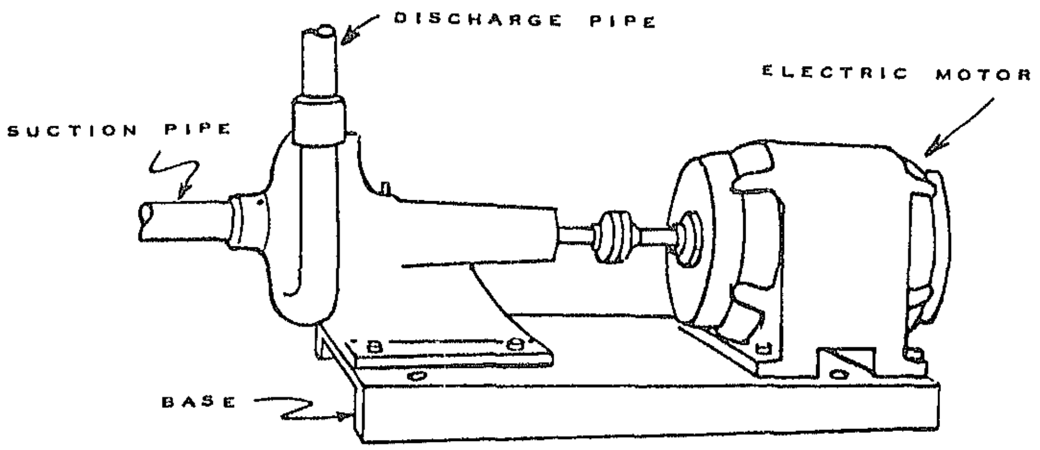
The vertical centrifugal pump may be submerged or exposed. The exposed pump is set in a watertight sump at an elevation that will accommodate the suction lift. The submerged pump is set so the impeller and suction entrance are under water at all times. Thus, it does not require priming, but maintenance costs may be high as it is not possible to give the shaft bearings the best attention. Pumps of this kind usually are restricted to pumping heads of about 50 feet.

Turbine Pumps

ll turbine pump is adapted for use in cased wells or where urface is below the practical limits of a centrifugal pump.

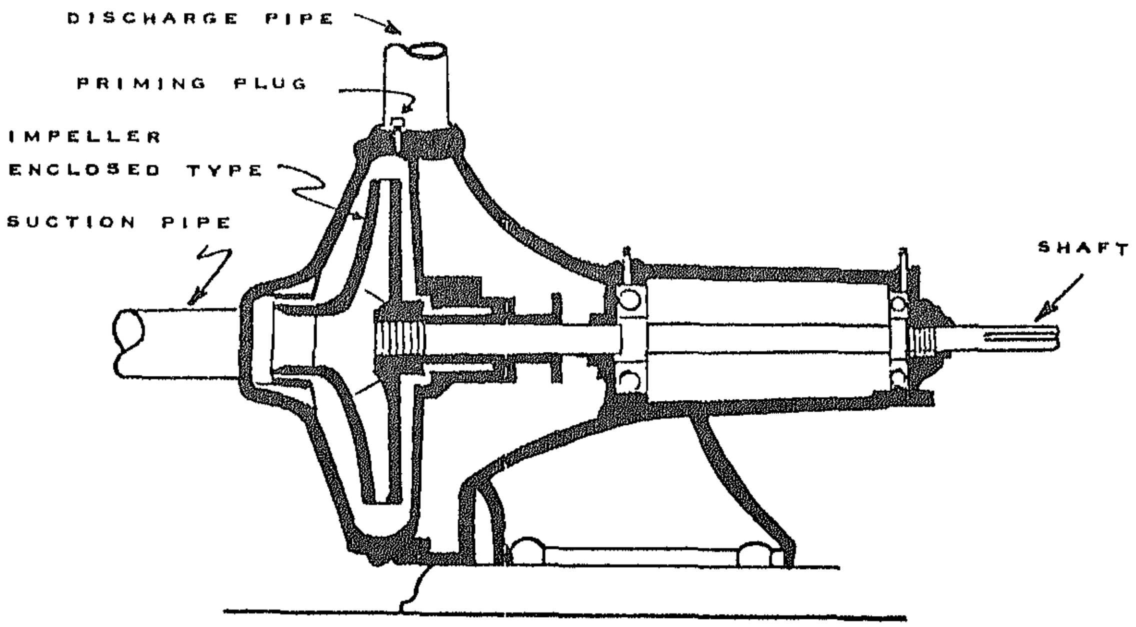
he proper selection of a turbine pump the following must be

pth of well
nside diameter of casing
epth of static water level
rawdown/yield relationship curve
epth of screen section
ump capacity requirements



DIRECT CONNECTED HORIZONTAL CENTRIFUGAL PUMP

INTERNAL COMBUSTION OR ELECTRIC MOTOR MAY BE USED



CROSS SECTION OF MODERN HORIZONTAL CENTRIFUGAL PUMP

SINGLE SUCTION ENCLOSED IMPELLER

Figure 6-1. Horizontal Centrifugal Pump

All this is essential in selecting a pump that will fit inside the well, deliver the required amount of water at the desired pressure, and to assure that the bowls are submerged during operation.

Turbine pumps are equipped with impellers that are fitted inside a bowl-appearing case. Each of these units is known as a stage. Stages are added to develop additional head. You can determine the number of stages needed for a pump installation by the amount of water required and the pressure at which it is to be delivered.

Turbine pumps may be either oil-lubricated or water-lubricated. The oil-lubricated pump has an enclosed shaft that oil drips into, thus lubricating the bearings. The water-lubricated pump has an open shaft. The bearings are lubricated by the pumped water. If there is any fine sand being pumped, select the oil-lubricated pump because it will keep the sand out of the bearings. If the water is for domestic use, it must be free of oil. So you should use the water-lubricated pump.

Turbine pumps are available with either semi-open or enclosed impellers. The semi-open impeller will tolerate more sand than the enclosed impeller and it can be adjusted. The enclosed impeller claims to retain high efficiency without adjustment. Figure 6-2 shows a typical deep-well turbine pump.

The submersible pump is simply a turbine pump close-coupled to a submersible electric motor attached to the lower side of the turbine. Both pump and motor are suspended in the water, thereby eliminating the long-line shaft and bearing retainers that are normally required for a conventional deep-well turbine pump. Operating characteristics are the same as for deep-well turbine pumps. Figure 6-3 shows a typical submersible pump.

Propeller Pumps

Propeller pumps are chiefly used for low-lift, high-gallonage conditions. There are two types of propeller pumps, the axial-flow or screw type, and the mixed-flow. The major difference between the axial-flow and the mixed-flow propeller pumps is in the type of impeller (Figure 6-4).

The principal parts of a propeller pump are similar to the deep-well turbine pump in that they have a head, an impeller, and a discharge column. A shaft extends from the head down the center of the column to drive the impeller. Some manufacturers design their pumps for multi-stage operation by adding additional impellers where requirements demand higher heads than obtainable with single-stage pumps.

Where propeller pumps are adapted, they have the advantage of low first cost and the capacity to deliver more water than the centrifugal pump for a given size impeller. Also, for a given change in pumping lift, the propeller pump will provide a more nearly constant flow than a centrifugal pump. Their disadvantage is that they are limited to pumping against low heads.

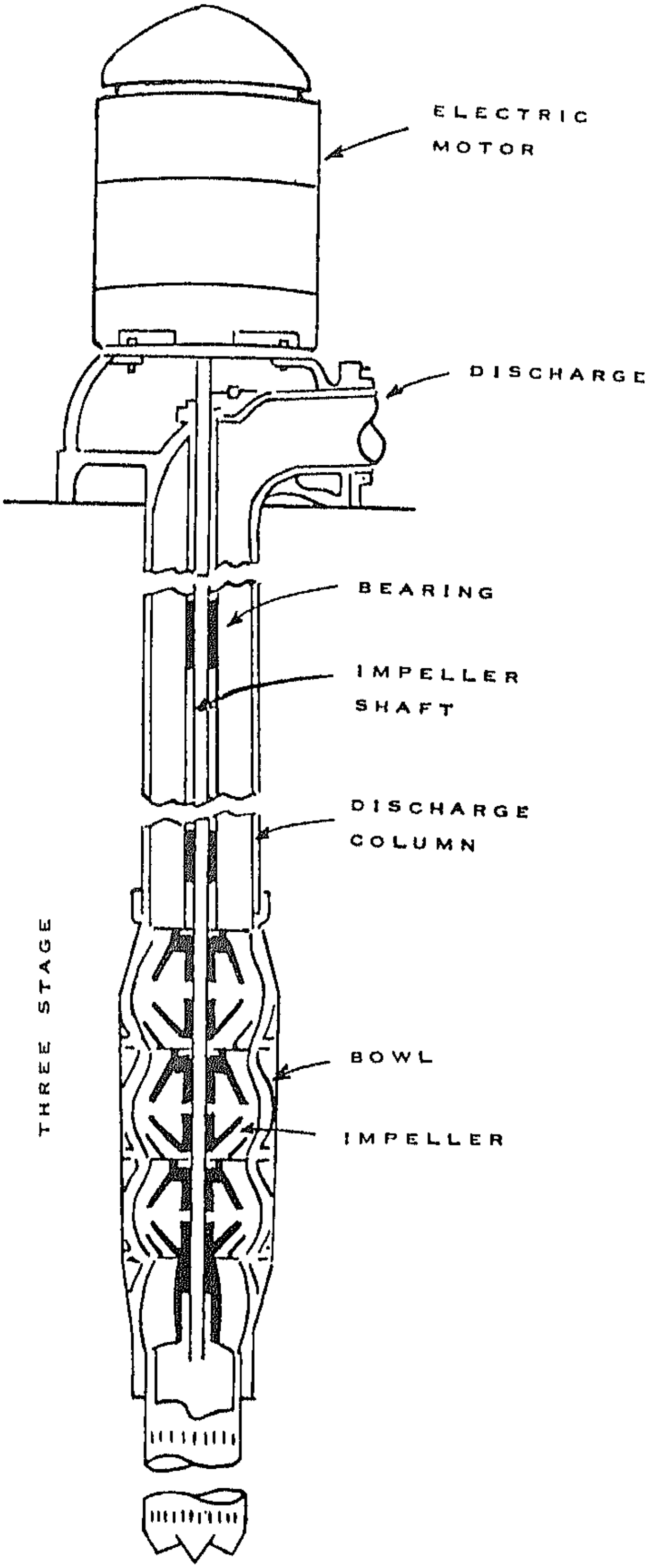


Figure 6-2. Deep-well Turbine Pump

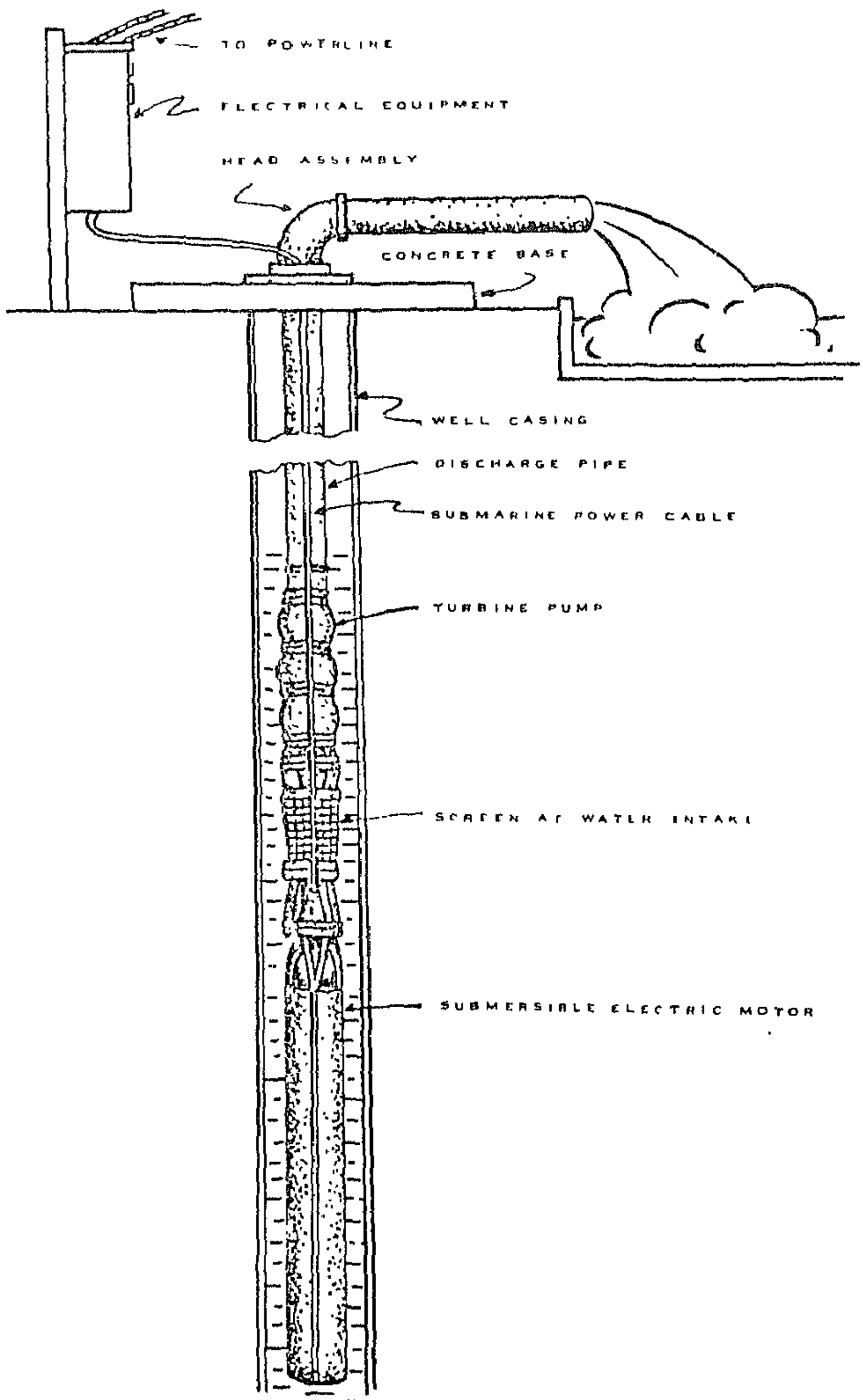


Figure 6-3. Submersible Pump

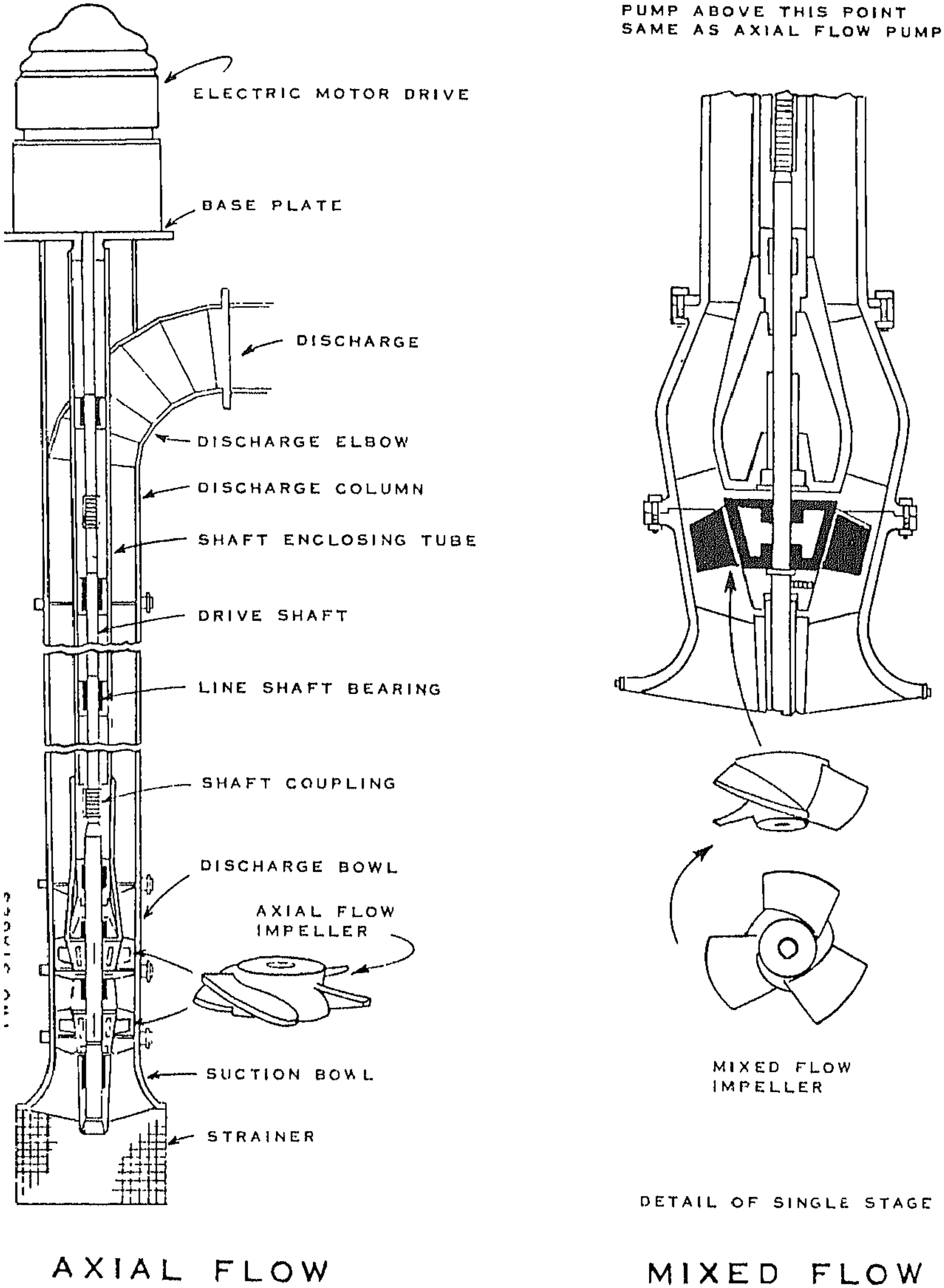


Figure 6-4. Propeller Pumps

Axial-Flow Pumps

The axial-flow single stage propeller pumps are limited to pumping against heads of around 10 feet. By adding additional stages, heads of 30 to 40 feet are obtainable. These pumps are available in sizes ranging from 8 to 48 inches. The impeller has several blades like a boat propeller. The blades are set on the shaft at angles determined according to the head and speed. Some manufacturers have several propellers for the same size of pump, thereby providing for different capacities and heads. The water is moved up by the lift of the propeller blades and the direction of flow does not change as in a centrifugal pump. A spiral motion of the water results from the screw action, but may be corrected by diffusion vanes.

Mixed-Flow Pumps

The mixed-flow propeller pump is designed especially for large capacities with moderate heads. The smaller size single-stage pump will operate efficiently at low heads of from 6 to 26 feet. The multiple stage and large size pumps will handle heads up to approximately 125 feet. They are generally built in sizes ranging from 10 to 30 inches. The mixed-flow pump uses an open vane curved blade impeller which combines the screw and centrifugal principles in building up the pressure head. They have a capacity range of from 1,000 gpm to approximately 50,000 gpm depending on size, stages, and heads. The mixed-flow pump operates more efficiently against higher heads than the axial-flow propeller pump.

Table 6-1 lists the advantages and disadvantages of commonly used irrigation pumps.

Pump Characteristic Curves

The importance of pumping efficiency cannot be over emphasized. Anyone buying a pump should insist on seeing the pump curves before making a decision.

There are four different characteristic curves that are most commonly provided by the manufacturer. Some manufacturers use tables, but the most common approach is to use graphs. The four types of curves are illustrated in Figure 6-5.

Total Dynamic Head Versus Discharge

This curve is often referred to as the TDH-Q curve and relates the head produced by the pump as a function of the discharge. Generally these curves will dip downward to the right although there are some pumps which will have multiple humps. The most common curves for irrigation pumps have a shape similar to the one in Figure 6-5.

The curve usually shows the head for only one stage for multi-stage pumps. It is usually necessary to use more than one stage to create the required pumping head with one stage discharging directly into another. The head produced by such a pump is directly proportional to the number of stages; that is, for a given capacity, a two-stage pump will produce twice the head of a single-stage pump, etc.

Table 6-1 Advantages and Disadvantages of Commonly Used Irrigation Pumps

HORIZONTAL CENTRIFUGAL PUMPS

Advantages	Disadvantages
High efficiency is obtainable.	Suction lift is limited, should be within 20 feet of water surface.
Efficiency remains high over a range of operating conditions.	Requires priming.
Adaptable to a range of operating conditions.	Loss of prime can damage pump.
Simple and economical.	May overload if head is decreased.
Easy to install.	Available head per stage is limited.
Does not overload with increased head.	
Produces a smooth even flow.	

VERTICAL CENTRIFUGAL PUMPS

Advantages	Disadvantages
May be exposed or submerged	Maintenance costs may be high to the shaft and bearings.
Submerged pump does not require priming.	Usually restricted to pumping heads of no more than 50 feet.
	May overload if head is decreased.
	More expensive than horizontal centrifugal.

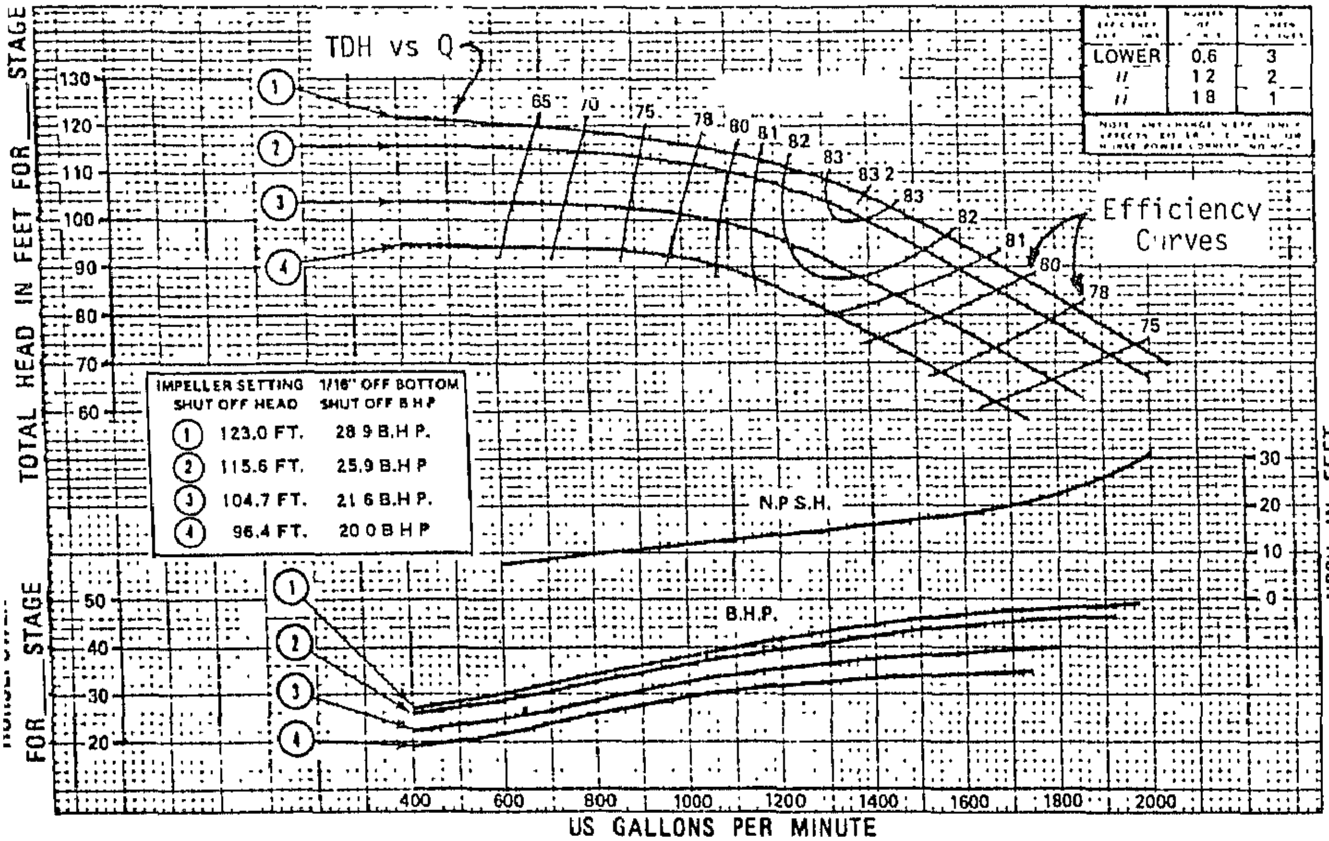
TURBINE PUMPS

Advantages	Disadvantages
Adapted for use in wells.	Higher initial cost than centrifugal.
Adapted for use where water surface fluctuates.	Requires closer setting than centrifugal pumps.
Can be adapted for high heads and large discharges.	Efficient over narrower range of operating conditions than centrifugal pumps.
Small chance of losing prime.	Not adaptable to change in speed.
	Requires additional stages for larger heads.
	Difficult to install and repair.

PROPELLER PUMPS

Advantages	Disadvantages
Simple construction.	Not suitable for suction lift.
Adaptable to high flow against low heads (0-25 feet for axial-flow pump) (6-45 feet for mixed-flow pump)	Requires proper clearances between walls and bottom of pump.
fficient at variable speeds.	
an pump some sand with water.	
eeds no priming.	

Figure 6-5. Typical Pump Performance Curve



14LD Curve No. 4805999 Impeller No. 2634705 1760 RPM

If a pump is operated against a closed valve, the head generated is referred to as the shut-off head. Shut-off head is shown in Figure 6-5. Note that the efficiency of the pump at this point is zero because the pump still requires energy to drive it. For turbine or centrifugal pumps it is necessary to know the shut-off head. The pipe on the discharge side must be capable of withstanding the shut-off head in case a valve is accidently closed on the discharge side.

For a turbine pump the manufacturer's reported efficiency is for a specific number of stages. If, for a specific application, the number of stages differs, then it is necessary to adjust the reported efficiencies upward or downward depending on the number of stages. Figure 6-5 indicates that efficiency values as graphed must be lowered 1.8 percentage points for only a single stage pump, lowered 1.2 percentage points for a two-stage pump, lowered 0.6 percentage point for a three-stage pump, and would remain unchanged for more than three stages.

Efficiency Versus Discharge

The efficiency discharge relationship is drawn as a series of envelope curves upon the TDH-Q curve in Figure 6-5. There is generally only one peak efficiency which is related to a specific discharge. If the pump can be operated at this discharge then for a given amount of energy input to the pump, the output work will be maximized.

Efficiencies vary between types of pumps, manufacturers and models. Generally, the larger pumps have higher efficiencies. The efficiency also is related to types of materials used in construction, the finish on the castings or machining, and the type and number of bearings used. For example, enameled impellers, which are smoother than bronze or steel, will result in a higher efficiency.

Efficiency is defined as the output work divided by the input work. See Chapter 8 for discussions on pumping plant efficiency.

Input Power Versus Discharge

The input power if referred to as the brake horsepower required to drive the pump. The curve is commonly called bhp-Q curve. It should be noted that even at zero discharge when the pump is operating against the shut-off head, an input of energy is needed.

The shape of the bhp-Q curve can take several different forms. The most common form for irrigation pumps is similar to the curve of Figure 6-5. In other instances the bhp-Q curve will have the highest horsepower demand at the lowest discharge rate and the required input power will continue to decline as Q increases. The shape of the bhp-Q curve is a function of the TDH-Q and Eff-Q curves.

Net Positive Suction Head Versus Discharge

The fourth characteristic curve is the net positive suction head required, NPSHR, versus discharge relation. The NPSHR is the amount of energy required to move the water into the eye of the impeller and is a function of the pump design. This characteristic also varies for different types of pumps, manufacturers and models. Its value is determined by the manufacturer from laboratory tests. The NPSHR is a function of pump speed, impeller shape, liquid properties, and the discharge rate. If sufficient energy is not present in the liquid on the intake side of the pump to move the fluid into the eye of the impeller, then the liquid will vaporize and pump cavitation will occur.

Theoretically, if a pump could be designed to produce a perfect vacuum at its center and it was being operated at sea level, the atmospheric pressure of about 14.7 psi acting downward on the surface would force water up the suction line to the pump a distance of 34 feet (14.7 psi x 2.31 ft/psi). In practice this is impossible first because a perfect vaccum cannot be created at the center of the impeller and secon because there are losses due to friction created by the flow through the suction line and losses due to turbulence at the entrance to the suction line and at the entrance to the impeller.

To assure that the required energy is available, an analysis must be made to determine the net positive suction head available, NPSHA. Th available head is a function of the system in which the system operates and can be calculated for all installations. If the NPSHA does not exceed the NPSHR then the pump will cavitate. The equation for computing NPSHA is as follows:

$$NPSHA = 144 \frac{Pa - Pv}{w} - h_f + z$$

where Pa = pressure, psia, on a free water surface, atmospheric

Pv = vapor pressure, psia, of the water at its pumping temperat

hf = friction loss in the suction line, ft of water

z = elevation difference, ft (suction lift) between pump cente line and water surface. If the suction water surface is below the pump centerline, z is negative.

w = unit weight of water, lb/ft3

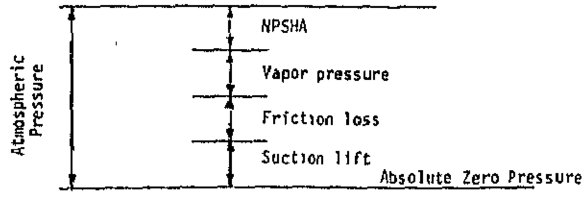


Figure 6-6 Schematic for NPSHA Versus Atmospheric Pressure, Suction Lift, Friction and Vapor Pressure

A person should keep in mind that there are many pump manufacturers and many pump models. If the first pump investigated does not fit the needs, then the designer should investigate other pumps. There should be pumps available to meet the particular situation. Also, do not expect a pump to maintain its peak efficiency over the years. Select a pump capable of filling the demands at a little less than its peak design efficiency.

Power Units

The power required to pump depends on (1) the quantity of water, (2) the total head or pressure against which it is pumped, and (3) the efficiency of the pump. See Chapter 8 for computing horsepower requirements of power units.

Many types of power units can be used for operating pumps. An old automobile engine belted to the pump may do the job at low initial cost, but operating cost is likely to be high and service unreliable. Money is often wasted by investing in old inefficient engines not suited to the job.

It must be remembered that a farm tractor used to furnish power will not be available for other farming operations and may require modification of the cooling system. Farm tractors are not built for continuous operation such as is needed to power an irrigation pump. If a tractor is used, it should be large enough so that it is not necessary to operate the engine at full throttle. Also, the motor should be equipped with safety devices.

Where available at reasonable rates, electricity is usually the most satisfactory source of power for irrigation pumping. Electric motors offer high efficiency, reliability, compactness, and low maintenance cost; which makes them especially desirable for operating pumping plants.

Internal combustion engines are most widely used where electric power is not available or where it is too expensive. These include gasoline and diesel engines. The former type may be adapted to burn natural gas, kerosene, or distillages. Proper cooling is very important when internal combustion engines are used for irrigation pumping.

Gasoline engines cost less initially than diesel engines and are better adapted to smaller loads and shorter operating hours. Diesel engines are best for heavy duty and generally give longer service. The choice of an internal combustion engine for a given job depends on the size of load, length of operating periods, and the required life of the engine.

Table 6-2 lists some of the advantages and disadvantages of various types of power units.

Table 6-2 Advantages and Disadvantages of Various Power Units

DIESEL	
Advantages	Disadvantages
Variable speed allows variation of pumping rate and horsepower.	Service may be a problem.
Moderate depreciation rate.	High initial cost.
Can be moved from site to site.	
Fuel costs are usually lower than gasoline or LP.	

GASOLINE	
Advantages	Disadvantages
Variable speed allows variation of pumping rate and horsepower.	High depreciation rate.
Parts and service are usually available locally on short notice.	High maintenance cost.
Can be moved from site to site.	Fuel costs may be high.
	Fuel pilferage may be a problem.

NATURAL GAS	
Advantages	Disadvantages
Variable speed allows variation of pumping rate and horsepower.	Requires natural gas pipeline.
Moderate depreciation rate.	Not easily moved from site to site.
Low energy costs if gas is available at favorable rates.	

LP GAS	
Advantages	Disadvantages
Variable speed allows variation of pumping rate and horsepower.	Special fuel storage must be provided.
Parts and service are usually available locally on short notice.	Fuel costs may be high.
Moderate depreciation rate.	

ELECTRIC MOTOR	
Advantages	Disadvantages
Long life, low depreciation.	Constant speed, pumping rate can be reduced only by increasing head on system.
Low maintenance.	Requires three-phase power or phase converter.
Easily adapted to automatic controls.	Not easily moved from site to site because of the necessary electric service.
High operating efficiency.	Electrical storms may disrupt service, sometimes many miles from the site.
Easy to operate.	
Requires no fuel storage.	

Irrigation pumping plants often operate for long periods without attention. For this reason, power units should be equipped with safety devices to shut them off when changes in operating conditions occur that might cause damage. Such changes include when: (1) oil pressure drops, (2) coolant temperature becomes excessive, (3) pump loses its prime, (4) the discharge pressure head drops, or (5) oil level drops.

Pumping Plant Head

For proper pump and power unit selection the total dynamic head (TDH) must be computed. A knowledge of certain terms is necessary to compute the TDH and in discussing pumping plant head requirements.

Pressure-Pressures are usually measured with a gauge. When water in a container is at rest, the pressure at any point consists of the weight of water above the point (i.e., water weighs 62.4 pounds per cubic foot or 0.433 pounds per square inch (psi). The column of water is referred to as head and is expressed in feet. Head can be converted directly to pressure in evaluating systems by multiplying head by 0.433. Conversely, pressure can be converted to head by multiplying pressure by 2.31.

Dynamic Head - An operating sprinkler system has water flowing through the pipes. Thus, the head under which the system is operating is dynamic. Dynamic head is made up of several components as follows:

1. Static Head - Static head is a vertical distance. It is the distance through which the pump must raise the water.

   Where the water source is below the pump centerline, the distance from the water surface to the pump centerline is called the static suction lift or head. For centrifugal pumps, friction losses in the suction pipe and fittings should be included.

   The elevation difference between the centerline of the pump and the point of discharge is referred to as the static discharge head.

   Total static head is the summation of the static suction lift or head and the static discharge head.

2. Pressure Head - Sprinkler operating pressure converted to head is termed pressure head. The sprinkler converts pressure head to velocity head which carries the water out into its trajectory.

3. Friction Head - The friction caused by water flowing through a pipe decreases pressure in the pipe. The pump must overcome this loss which is termed friction head which is a function of size, type, condition and length of the pipe and water velocity in the pipe. Similar losses are incurred by water flowing through pipe fittings. Losses through specific fittings can be stated as an equivalent length of pipe of the same diameter and can be taken from Appendix C.

Losses in fittings and valves can also be computed by the formula:

$$h_f = K\frac{v^2}{2g}$$

Where: h_f = friction head loss in feet

K = resistance coefficient for the fitting or valve

$\frac{v^2}{2g}$ = velocity head in feet for a given discharge and diameter

Values of the resistance coefficient K may be taken from Appendix C.

4. Velocity Head - Flowing water represents energy and work must be done by the pump to impart motion to the water. The resistance to movement by the water is similar to friction. Velocity head is computed by squaring the velocity and dividing by two times acceleration due to gravity or

$$H_v = \frac{v^2}{2g}$$

Velocity is measured in feet per second and can be computed from:

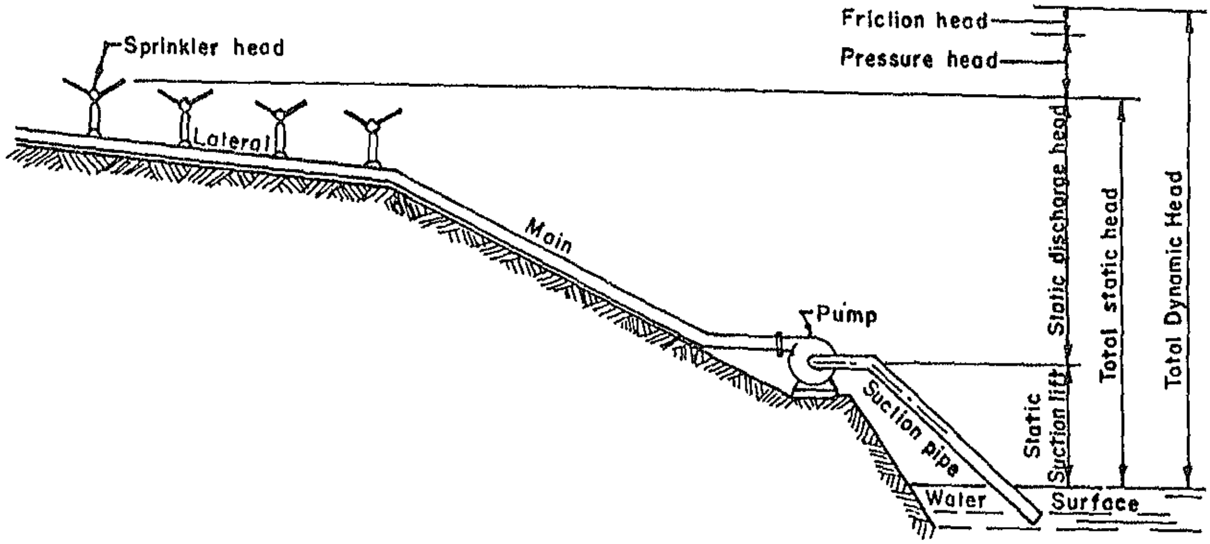
$$V = \frac{0.408 \times gpm}{D^2}$$

Where gpm is discharge in gallons per minute and D is inside diameter of the pipe. Hv values are small and usually negligible unless large volumes are pumped through small diameter pipes.

Total Dynamic (TDH) - As mentioned, this is a very important factor in selecting the pumping unit. An accurate estimate is necessary to assure a satisfactory pump performance. First calculate the components discussed in the preceding paragraphs and add them together:

Total dynamic head = total static head + pressure head + friction head

See Figure 6-7 for a sketch showing the above terms. NEH Section 15, Chapter 8, Figures 8-19, 8-20, and 8-21 give examples of computing TDH for centrifugal pumps, turbine pumps, and propeller pumps, respectively.



TDH = total static head + pressure head + friction head

Where

1. Total static head = static discharge head + static suction head or lift

   a. Static discharge head is the difference is elevation between the centerline of the pump and the elevation of the sprinkler orifice or other point of use.

   b. Static suction lift is the difference in elevation between the water surface elevation being pumped and the centerline of the pump.

2. Pressure head is the average operating pressure for the lateral.

3. Friction head is pressure loss due to friction in the main, lateral suction pipe, and fittings and valves.

Figure 6-7 Elements of A Pumping Plant and the Corresponding Elements of Total Dynamic Head Used In Calculating Pump and Power Requirements

DISTRIBUTION PIPELINES

SELECTION

When selecting the distribution pipelines, both the annual installation cost and the annual operating cost should be considered. The installation cost of smaller diameter pipelines is less, but the operating cost (pumping power cost to overcome pipeline friction) will be more than for larger diameter pipelines. The most economical size would be the one with the smallest sum of annual installation and operating costs. This requires the comparison of the sum of installation and operating costs of the various pipeline sizes being considered.

The annual installation cost is computed by multiplying the initial installed cost by the appropriate amortization factor. The amortization factor can be found from Chapter 9, Table 9-1. Use the same life expectancy and interest rate that will be used in the economic evaluation.

The annual operating cost of a pipeline essentially consists of only the pumping power fuel cost to overcome pipeline head loss (friction) since the total static head and pressure (operating) head remains constant when comparing pipeline sizes, only the friction and velocity head change. The annual fuel cost can be found by using the following formulas.

$$\text{Fuel cost per yr} = \frac{\text{bhp} \times \text{hr/yr} \times \text{cost/unit of fuel}}{\text{bhp-hr/unit of fuel } \underline{1}/}$$

Where $$\text{bhp} = \frac{\text{TDH} \times Q}{3690 \times \text{pump eff.} \times \text{drive eff.}}$$

bhp = brake (dynamometer) horsepower

TDH = total dynamic head, feet

Q = capacity in gpm

1/ bhp-hr/unit of fuel is shown in Chapter 8, Table 8-1.

stored in the fluid due to its mass and velocity. When a value is quickly closed, the velocity is suddenly stopped. Since liquids are nearly incompressible, this energy cannot be absorbed, and the momentum of the fluid causes a shock called "water hammer." This may represent excessively high momentary pressures. The shutting down of a pump and then restarting it before the system comes to rest is also a cause of excessive surge pressure. Four factors that greatly influence the magnitude of water hammer (surge pressure) are:

1. Length of pipeline (the longer the line, the greater the shock)
2. Velocity
3. Closing time of valves
4. Diameter of pipe

Minimum valve closing times, pressure relief valves, and thrust blocks are utilized to help minimized and/or control surge pressures. Since velocity is the primary factor contributing to excessive surge pressure, the velocity of pipelines generally should be limited to five feet per second. Also, irrigators should be advised against quick closing of valves and restarting pumps before the system returns to static rest. Another factor that influences surge is the instantaneous stopping of electric motors whereby a backlash condition is created and higher than normal pressures occur.

When pipeline working pressures and velocities exceed the limits generally recommended in the SCS technical guide standards, special considerations should be given to protect the pipeline for flow conditions and the total pressure generated during a surge condition. Measures utilized may include pressure-relief valves with control of valve opening and closure times. The total pressure subjected to the mainline pipe during a surge condition is equal to:

$$P\ Total = Po + Ps$$

where P Total = total system pressure during a surge (psi)

Po = the operating pressure at the time of the surge(psi)

Ps = the surge pressure: an increase in pressure over and above the existing operating pressure at the time of the surge(psi)

The approximate magnitude of the surge pressure (Ps) for gradual closure conditions may be calculated by the following formula (reference - Rainbird Design Guide For Turf and Ornamental Irrigation Systems 1976, p. 54)

$$Ps = \frac{V \times L \times .07}{t}$$

where V = original velocity of flow at time of surge (ft/sec)

L = the length of the straight mainline pipe which extends between the water source and the point in the mainline (valve or pump location) where the flow was stopped (feet).

t = the approximate time required to stop the flow of water (i.e. time to close the valve - seconds)

Closure is considered instantaneous whenever t is less than 2 L/U where U is the velocity (fps) of a pressure wave in the pipe as follows:

$$U = (E/R)^{0.5} \quad (1/(1+ED/EpT))^{0.5}$$ [1]

where E = modulus of elasticity of water, 43.2×10^{6} psf

R = density of water, 1.94 lb sec^{2} per ft^{4}

D = diameter of pipe, ft

Ep = modulus of elasticity of pipe material, 57.6×10^{6} psf for Type 1, Grade 1 or 2 PVC pipe

T = thickness of pipe wall, ft

For instantaneous closure the maximum surge pressure may be calculated as follows:

$$Ps = RUV$$ [1]

where Ps, R, U, and V are as defined above.

[1] Reference - Standard Hbk. for Civil Eng. by F.S. Merritt McGraw-Hill, Inc. Page 21-33.

If it is not practical to keep the total pressure during a surge equal to or less than the working pressure rating of the pipe, the total system pressure during the surge should be less than 75 percent of the burst pressure rating of plastic pipe. The burst pressure rating of plastic (PVC) pipe is approximately 3.0 times the nominal working pressure rating (PVC 1120, 1220, & 2120, see ASTM D 2241)

Safety Devices

Figure 6-8 illustrates many of the devices that enhance the water delivery process and protect the pipeline investment. The relative location of each of these devices is important and alteration of their location should be reviewed carefully.

Manual Valves

valves are principally used to isolate sections of a system for
ion, for purpose of repair and for manual drain valves. The
should be gate valves rather than globe valves to keep friction
minimum. Generally, cross handles are preferred as the access
ves is through valve sleeves. A sprinkler control valve key
open them. Non-rising stems are often required.

y a gate valve is used as a flow control, but its use is
hydraulically simple systems.

Check Valves

Check valves are used to limit water flow to one direction. Check valves are utilized at the pump discharge to prevent the backflow water into the well and are required to prevent chemicals from flowing back into the ground water formation when chemical injection is used.

Check valves can be of the swing-check variety (which depends on its own weight to close against a backflow), spring loaded variety (which is closed against a backflow by a retracting spring), or the float variety (in which a float is pushed out of the way by regular water flow but pressed into the upstream opening by backflow).

Pressure Reducing Valve

The pressure reducing valve provides control over the downstream flow rate and/or pressure. These control valves are often used to prevent rapid buildup of line pressures during pump start-up.

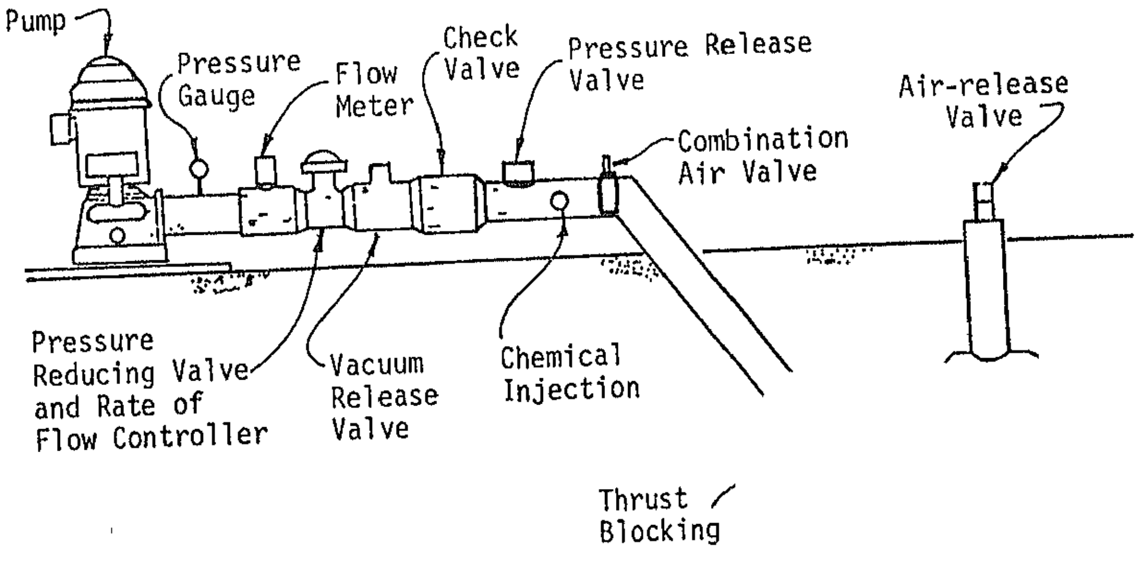


Figure 6-8. Illustration of Valve I

nti-Syphon or Backflow Prevention Units

outh Carolina passed legislation June 6, 1986 (SC Code of Laws, Section 6-1-140) requiring installation of an anti-syphon or backflow preven-ion device on any irrigation system designed or used for the applica-ion of fertilizers, pesticides or other chemicals. Effective June 6, 988, all irrigation systems must be in compliance with this new law. ı anti-syphon device could consist of the following components:

a) Functional Check Valve. Such valve shall be equipped with replaceable disc and shall be serviceable with conventional tools. This valve shall be located in the irrigation supply line between the irrigation pump and the point injection of fertilizer, pesticide or chemical. This valve, when installed, shall be on a horizontal plane and level.

) Low Pressure Drain. Such drain shall be at least three-fourths inch in diameter. It shall be located on the bottom of the horizontal pipe between the functional check valve and the irrigation pump. It must be level and must not extend beyond the inside surface of the bottom of the pipe. The outside opening of the drain shall be at least two (2) inches above grade.

) Vacuum Relief Valve. The low pressure drain shall include a vacuum relief valve as a component part, or shall be complemented with a separate vacuum relief valve. The separate vacuum relief valve shall be at least three fourths inch in diameter and shall be located on the top of the same horizontal pipe section in which the low-pressure drain is located.

ain Valves

ain valves can be either manual or automatic and are used to drain the ter from pipe lines. Manual drain valves are usually used on distri-ion lines which are continually under pressure. When the system is iterized, the valve is opened and the water is drained out of the es. Often pressurized air is also introduced at other points of the tem to clear out any pockets of water caused by low pipe lines. ual drain valves are normally located at lower pints of the system and uld be an angle valve which incorporates a flexible and replaceable t.

omatic drain valves are usually a spring and ball combination and are d in lateral lines which are under pressure only when the sprinklers operating. When the water pressure in the pipe reduces, the spring relieved of the pressure contracting it, it expands, pushing the ball the seat to allow water to flow through it to the atmosphere.

ssure Regulating Valves

ssure regulating valves have an automatic internal throttling action reduce high upstream pressures to a constant downstream pressure. in limits, a pressure regulator can throttle a wide range of higher sures to deliver the constant downstream pressure. There is always nherent loss through the regulator itself due to friction, in

addition to the throttling action. They cannot increase pressure. A given pressure regulator can deliver a constant downstream pressure at several flow rates. If a pressure regulator is placed upstream of a gate valve, the flow rate through the combination can be varied by opening or closing the gate valve. However, at all flow rates the maximum discharge pressure of the regulator will be the same. A pressure regulator only creates a constant, desired pressure immediately downstream of itself. Further downstream the pressure will be different.

Pressure-Release Valves

Pressure-release valves are attached to a pipeline and exhaust water from the pipeline into the atmosphere when the pressure in the pipeline exceeds a set value. They are located where high pressures will occur, such as at the bottoms of hills. They are also located immediately upstream of valves which could create sudden pressure buildups if closed quickly. Pressure relief valves do not prevent pressure fluctuations; they do prevent water pressures in the line from exceeding set valves.

Air Valves

General

There has been confusion in the industry as to the difference between an air-release valve, air-and-vacuum valve and a combination air valve. First it must be stated that these valves are for liquid systems and not for air or gas systems. To clarify the difference between these valves, the following will describe the specific purpose, function and operation of each valve.

Air-Release Valves

An air-release valve can be described as a device which will automatically release accumulated small pockets of air from high points in a system while that system is in operation and under pressure.

If we stop to consider some of the problems associated with air in a system, we can better understand how air-release valves can be utilized to eliminate those problems.

First of all, as a function of nature, some of the air entrained in a system will settle out of the liquid being pumped and collect at high points within that system. If no provision is made to remove this air from the high points, a small pocket of air will grow in size as additional pockets of air accumulate. This action will progressively reduce the effective area available to the flow of liquid and create a throttling effect as would a partially closed valve. The degree to which the flow is reduced and some of the ensuing problems are described in the following paragraphs.

In many instances, the liquid flow velocity will be sufficient to partially break up an enlarging pocket of air and flow a portion of it downstream to lodge at yet another high point. This ability of the flow velocity to trim back the size of an air pocket, as it grows larger, may prevent the flow rate from being drastically reduced. However, as a result of the throttling effect caused by the presence of this remaining air, the flow rate will always be less than intended and power consumption will be increased.

This type of problem is difficult to detect and if allowed to go uncorrected, constitutes a constant drain on system efficiency and will thereby increase operating costs.

In more extreme instances, it is actually possible for an enlarging pocket of air collecting at a high point or a series of high points within a system, to create a restriction to such a degree that the flow of liquid is virtually stopped or at the least greatly reduced. In a severe situation such as this, the problem is more easily identified and the installation of air release valves at high points in the system should be taken as a corrective measure to remove the restrictive pockets of air, thereby restoring system efficiency.

Of a more serious nature is the factor that sudden movements of these air pockets can result in a rapid change in the velocity of the liquid being pumped. The dyanmics involved in this change of velocity can be substantial and can lead to high pressure surges and other destructive phenomenon. As we can see, the problems associated with air in a system can range from mild but costly to severe and potentially destructive. The ideal situation is of course to anticipate those problems as outlined earlier and prevent the accumulation of air through the installation of air-release valves at all high points within a system, thereby avoiding the negative consequences described.

Operation of Air-Release Valves

First of all, consider the valve installed at a high point within the system, filled with liquid and under system pressure.

Now, during system operation, as small amounts of air enter the valve from the system, they will displace the liquid within the valve and lower its level relative to the float. When the liquid level has been lowered to the point where the float is no longer buoyant, the float will drop. This action opens the valve orifice and allows the air which has accumulated in the upper portion of the valve body to be released to the atmosphere. As this air is released, the liquid level within the valve once again rises, lifting the float and closing the valve orifice. This cycle automatically repeats itself as often as necessary. The ability of the valve to open and release accumulated air under pressure is achieved through the use of a leverage mechanism. When the float is no longer buoyant, this mechanism produces a greater force to open the valve than the system pressure produces against the valve orifice, which attempts to hold the valve closed. Accordingly, for a given air-release

valve, the higher the system pressure, the smaller the orifice diameter must be allow the valve to open and release accumulated air. Conversely, in the same valve, the lower the system pressure, the larger the orifice diameter that can be used to release accumulated air.

It should be noted, an air-release valve is intended to release pockets of air as they accumulate at high points during system operation. It will not provide vacuum protection nor will it vent large quantities of air quickly on pipeline fill, air-and-vacuum valves are designed and used for the purpose.

Air-release valves should always be installed on the discharge side of the pump having a suction lift and should be as close to the pump check valve as possible.

Air-and-Vacuum Valves

An air-and-vacuum valve (also referred to as air-vacuum-release and air-vent-and-vacuum release) can be described as a float operated device, having a large discharge orifice equal in size to its inlet port, which will automatically allow a great volume of air to be exhausted from or admitted into a system as circumstances dictate.

If we consider its use on pipeline service, we would find the following conditions prevail:

Prior to filling, a pipeline is thought to be empty. But this is far from true, for in reality it is filled with air and the presence of this air must be taken into consideration when filling the pipeline. It must be exhausted in a smooth and uniform manner to prevent pressure surges and other destructive phenomenon from taking place.

In addition, air must be allowed to re-enter the pipeline in response to a negative pressure in order to prevent a potentially destructive vacuum from forming. It should also be noted that even in those instances where vacuum protection is not a primary concern, some air re-entry is still necessary to properly drain a pipeline.

To perform those functions as outlined above, air-and-vacuum valves are installed whereever there is a high point or a change in grade.

Operation of Air-and Vacuum Valves

As the line is filled, the air present in the pipeline is exhausted to atmosphere through air vacuum valves mounted at high points in the system. After all the air has been exhausted, water from the pipeline will enter the valve, lift the float and close the valve orifice. The rate at which air is exhausted is a function of a pressure differential which develops across the valve discharge orifice. This pressure differential develops as water filling the pipeline compresses the air sufficiently to give it an escape velocity equal to that of the incoming

fluid. Since the size of the valve controls the pressure differential at which the air is exhausted, valve size selection is a very important consideration.

At some time during system operation, should the interal pressure of the pipeline approach a negative valve due to column separation, draining of the pipeline, power outage, pipeline break, etc., the float will immediately drop away from the orifice, and allow a flow of air to re-enter the pipeline. This action will minimize the potential vacuum and protect the pipeline against collapse or other related damage. The size of the valve will dictate the degree to which the vacuum is minimized, therefore, valve size selection is once again a very important consideration.

The valve, having open to admit air into the pipeline in response to a negative pressure, is now ready to exhaust air as the need arises. This cycle will automatically be repeated as often as necessary.

One additional point must be made. While the system is in operation and under pressure, small amounts of air may enter the valve from the pipeline and displace the fluid. Even though the entire valve may eventually fill with air, the air-and-vacuum valve will not open. The system pressure will continue to hold the float against the valve orifice and keep the valve closed. To reiterate, an air-and vacuum valve is intended to exhaust air during pipeline fill and to admit air during pipeline drain. It will not open and vent air as it accumulates at high points during system operation, air-release valves are designed and used for that purpose.

Combination Air Valves

As the name implies, this valve combines the operating features of an air-and vacuum valve and air-release valve.

It is utilized at high points within a system where it has been determined that the functions of air-and-vacuum and air-release valves are needed to properly vent and protect a pipeline.

The valve is available in two body styles, the single housing combination and the custom built combination.

The single housing combination air valve is utilized when compactness is preferred or when the potential for tampering exists due to accessibility of the installation. This style is most popular in the 1", 2" and 3" sizes with the 4" and 6" sizes used to a lesser degree.

The custom built combination air valve is a standard air-release valve piped with a shut off valve to a standard air-and-vacuum valve. It has greater versatility than the single housing style because many different model air-release valves with a wide range of orifice sizes can be utilized. This style is most commonly used in sizes 4" through 16".

When there is doubt as to whether an air-and-vacuum valve or a combination air valve is needed at a particular location, it is recommended that the combination air valve is selected to provide maximum protection.

Thrust Blocks

Thrust blocks are important components of irrigation water conveyance systems. They are required at abrupt changes in pipeline grade or alignment or changes in size to protect certain type pipelines from failure due to axial thrust of the pipeline. The thrust block should be designed in accordance with instructions contained in the appropriate Technical Guide for Irrigation Water Conveyance, Code 430.

Accessories

Booster Pumps

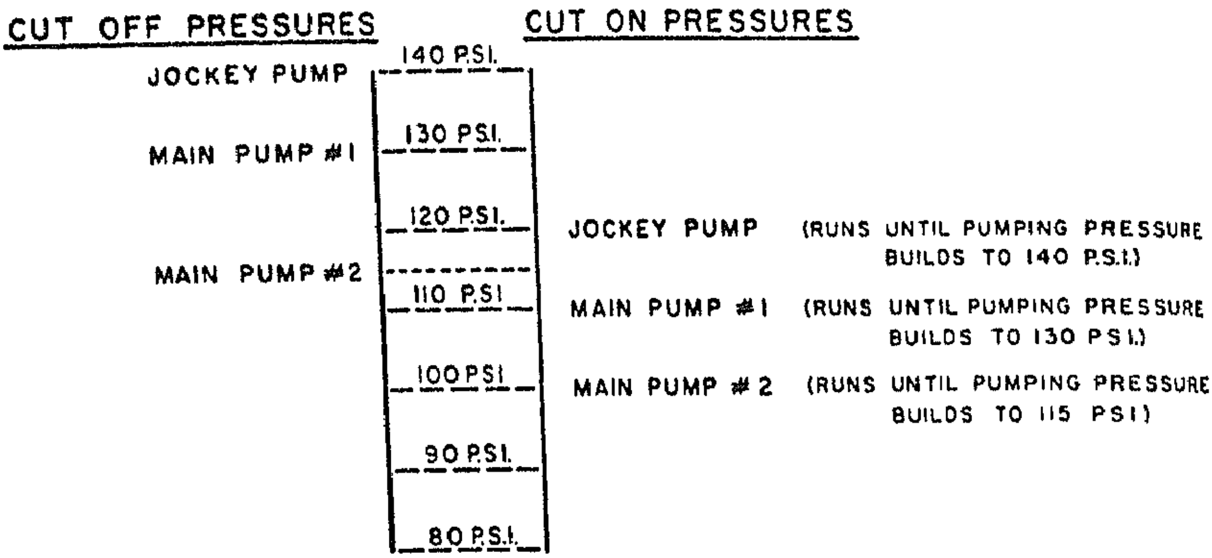
The booster pump can be used in a large irrigation system where compensations are necessary for pressure losses due to elevation. Booster pumps usually are of the centrifugal type which produce pressure by forcing movement of water. A booster does as its name implies, boosts the pressure. If the pressure at a certain point in a system is 30 psi at 20 gpm and the system requires 50 psi at 20 gpm at that point, a booster pump rated at 20 psi at 20 gpm can be installed in the line.

Pressure Tanks

Pneumatic pressure tanks are often used where a wide variance of gallonage requirements exists. The pressure tank will relieve the pump from kicking on for a short period of time when a low gallonage demand is made. The tank acts as a pressurized reservoir of water with expanding air forcing water out of the tank to fulfill low and infrequent water demands. Often times a small "jockey" pump is used to replenish the tank if low demands exist for a period longer than that for which the tank can provide.

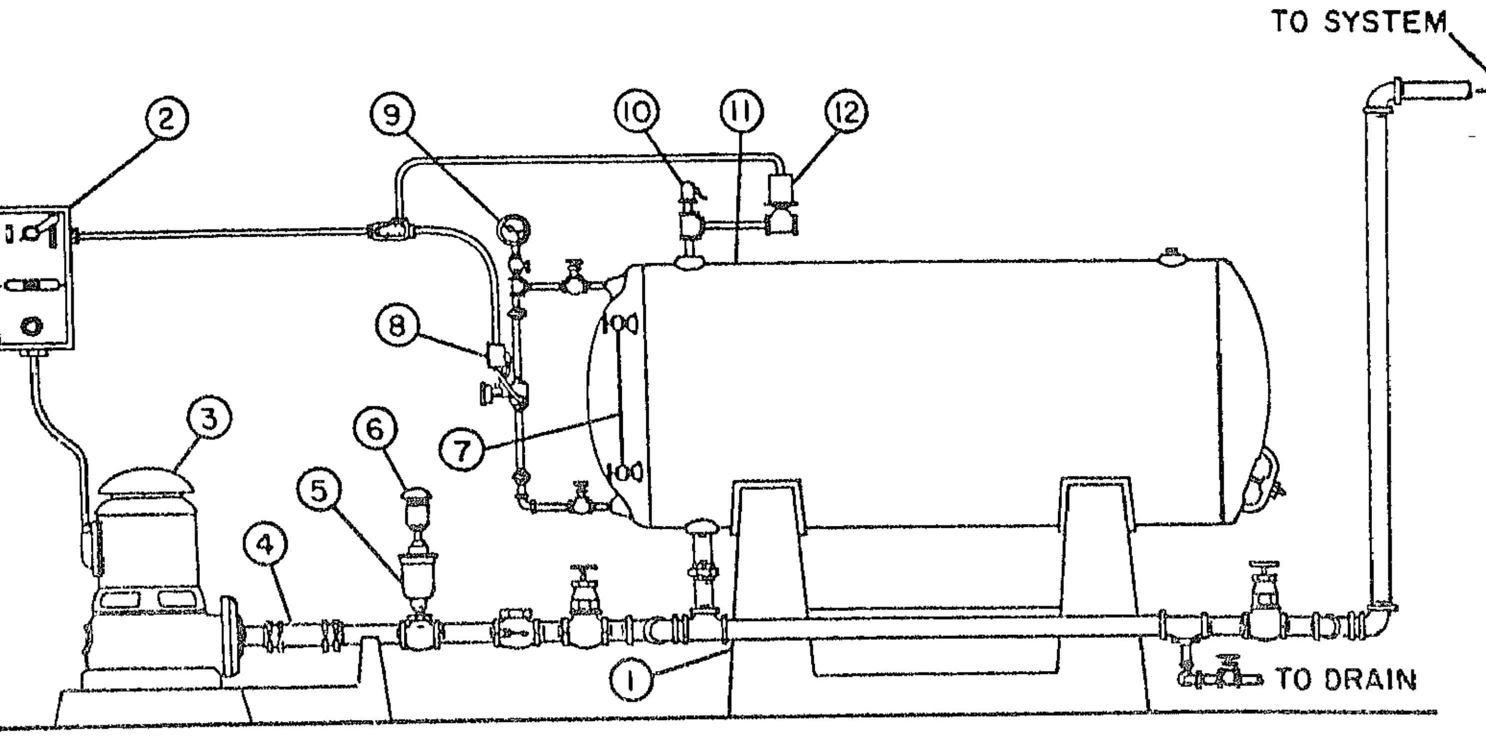
An example for the above case would be to have the "jockey" pump activate, by way of a pressure switch, at 120 psi. It would continue to run until pressure tank is replenished to 140 psi. If the demand was greater than the jockey pump, the pressure would continue to decrease until it reached the low limit of the pressure switch of the main supply pump. At that point the main pump would activate. If more than one main pump is used, they would be activated in turn as the pressure continued to drop. See the sketch on the following page.

If the pressure tank is too small for low gallonage demands, it will cause frequent and repetitive start-up of the pumps. This can also happen it the tank becomes waterlogged (the air is absorbed in the water causing a loss of the volume of air.)



An alternative for a pressure tank in a system where the demand varies widely is recirculation using a "dump" valve. Recirculation means to take the water supplied by the pump in excess of the water demanded of the system and dump it back into the supply. The dumping should be back into the reservoir as just repiping it back to the inlet can cause severe heating of the water when the demand is small, making the recirculated water volume large. A pressure relief valve is used to control the amount of water to be recirculated. Pressure tanks and the related equipment necessary for proper operation can become a maintenance headache so should be designed by an expert in the field of pumps and tanks.

Figure 6-9 is a typical system using a deep well pump with a pneumatic pressure tank. This system has an automatic air replenishing feature which can't normally be used when pumping from a reservoir using horizontal centrifugal pumps.



1—TANK SADDLES
2—COMBINATION STARTER
3—DEEP WELL PUMP
4—RUBBER HOSE CONNECTION
5—FLOAT VENT VALVE
6—AIR FILTER
7—WATER GAUGE
8—AUTOMATIC DUAL PRESSURE AND LEVEL CONTROL
9—PRESSURE GAUGE
10—PRESSURE RELIEF VALVE
11—PRESSURE TANK
12—SOLENOID VALVE

The water in the pump column (3) drains back into the well after each pumping cycle, replaced by air entering through the float vent valve (5). When the pump is started again, some of the air is forced into the tank, replenishing the air supply there. Excess air is vented to atomsphere by the float operated level control valve (8) opening the solenoid valve (12). The float in the control valve (8) will close the solenoid valve when the level is proper, readying the system for the next pumping cycle.

Figure 6-9. Typical System Using A Deep Well Pump
With A Pneumatic Pressure Tank

Pressure Gauges

Pressure gauges are desirable to have in a system so that the operator can operate the system in accordance with the system design. The system efficiency is often dependent upon operating pressures.

Flow Meters

Information from flow meters should decide the duration of pumping for many systems. A flow meter is indispensable in order to have efficient and economical irrigation operations. It will often reflect water supply problems from wells or other sources and provide data that will indicate repairs and maintenance needs in water supply equipment.

Chemical Injectors

A chemical injector is a device which injects a metered amount of liquid chemical (fertilizer, herbicides, pesticides, etc.) into the irrigation system. Three principal methods used in the injection of fertilizers and chemicals into irrigation systems are pressure differential, venturi vacuum, and metering pumps. Injectors are available to match most system needs and should be installed in the system ahead of the filter so that any undissolved chemicals will be filtered out before they enter the lines. If the injector is a pump which pumps chemicals from a tank into the system, it will not contribute any system pressure losses; however, when considering an injector, it is necessary to size it so that it will inject at a higher pressure than the main pump.

When chemicals are injected into irrigation systems there is a possibility of contamination of the water supply if the injection system is not carefully designed and safely managed. In many cases, the irrigation water supply is also a drinking water supply. The irrigator has the responsibility of protecting water quality. Water contaminated by chemicals could affect the health of other users of the water supply. If not properly used, chemigation exposes an irrigator to possible liability. Safety equipment exists which will protect both the water supply and the chemical purity in the storage tank. The possible dangers in chemigation include backflow of chemicals into the water source and water backflow into the chemical storage tank. Backflow to the water source will contaminate it. Backflow to the storage tank can rupture the tank or cause overflow, contaminating the area around the tank, and perhaps indirectly contaminating the water source. Once these problems are solved, the risk of liability in chemigation is not substantially greater than the liability which arises from the field use of agricultural chemicals utilizing other modes of application. For technical reasons such as reduced wind drift, rapid movement into the soil, and high dilution rates, chemigation could result in less risk of liability than the traditional methods of chemical application if proper backflow preventors are used.

Safety features recommended for internal combustion and electric irrigation pumping plants are shown in Figures 6-10 and 6-11. The safety equipment package consists of the following items which should be in good operating order before chemigation of any type.

1. A check valve must be installed between the pump and the chemical injection point on the irrigation pipe. This will prevent water from flowing from a higher elevation in the irrigation system back into the well or surface water supply. Thus water contaminated with chemicals will not flow back into the water source.

2. A vacuum breaker must be installed on the irrigation pipe between the pump and the check valve. This will allow air to enter the pipe when pumping stops so that water flowing back to the pump will not create a suction, pulling additional water and chemicals with it.

3. A low pressure drain should be provided to allow the irrigation pipe to empty without flowing back into the water source.

4. If chemical injector pumps are used, power supplies must be interconnected so that the injector pump cannot operate unless the irrigation pump is also operating. If the injector pump is mechanically driven, such as by a belt from the drive shaft of an internal combustion engine (Figure 6-10), this is not a problem. In this case, the power supplies are interconnected and, when the internal combustion engine stops, the injector pump will also stop. If, however, the chemical injector pump is electrically driven (Figure 6-11), then its electrical circuit must be interconnected with the irrigation pump circuit to assure that it stops when the irrigation pump stops. This precaution will assure that the chemical injector pump does not continue to inject into an empty irrigation pipeline, or worse, backwards into the water supply.

5. If chemical injector pumps are used, a check valve on the chemical injection line must be used to prevent water flow backwards from the irrigation system through the chemical injector pump and into the chemical storage tank. This will prevent dilution of the chemical by the irrigation water. It will also prevent possible rupture or overflow of the chemical storage tank and pollution of the surrounding area.

   Chemical injection line check valves are typically spring-loaded and require a large pressure to allow fluid to flow through them. These valves thus permit flow only when that flow is a result of the high pressure generated by a chemical injector pump. When the injector pump is not operating, chemicals will not leak due to the small static pressures created by the chemical level in the storage tank.

6. A valve must be provided for positive shutoff of the Chemical supply when the injection system is not in use. This may be a

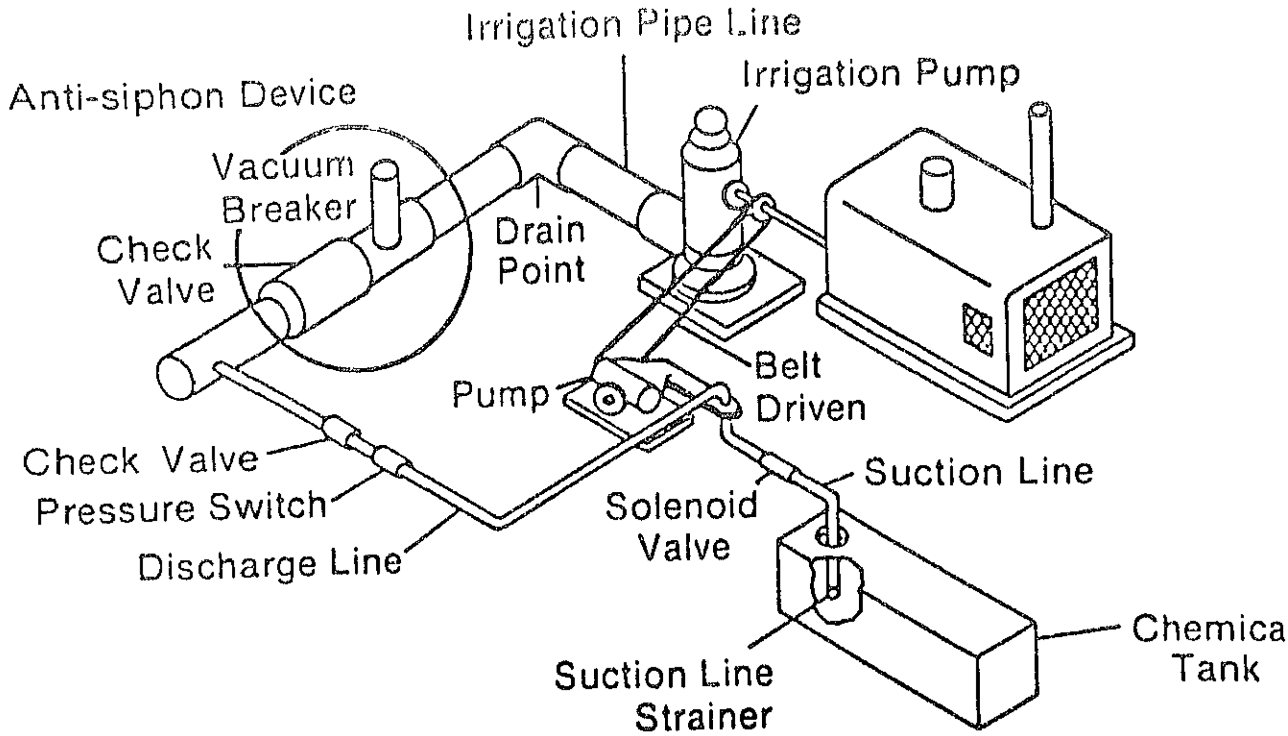


Figure 6-10. Chemigation safety equipment for internal combustion engine irrigation pumping plant.

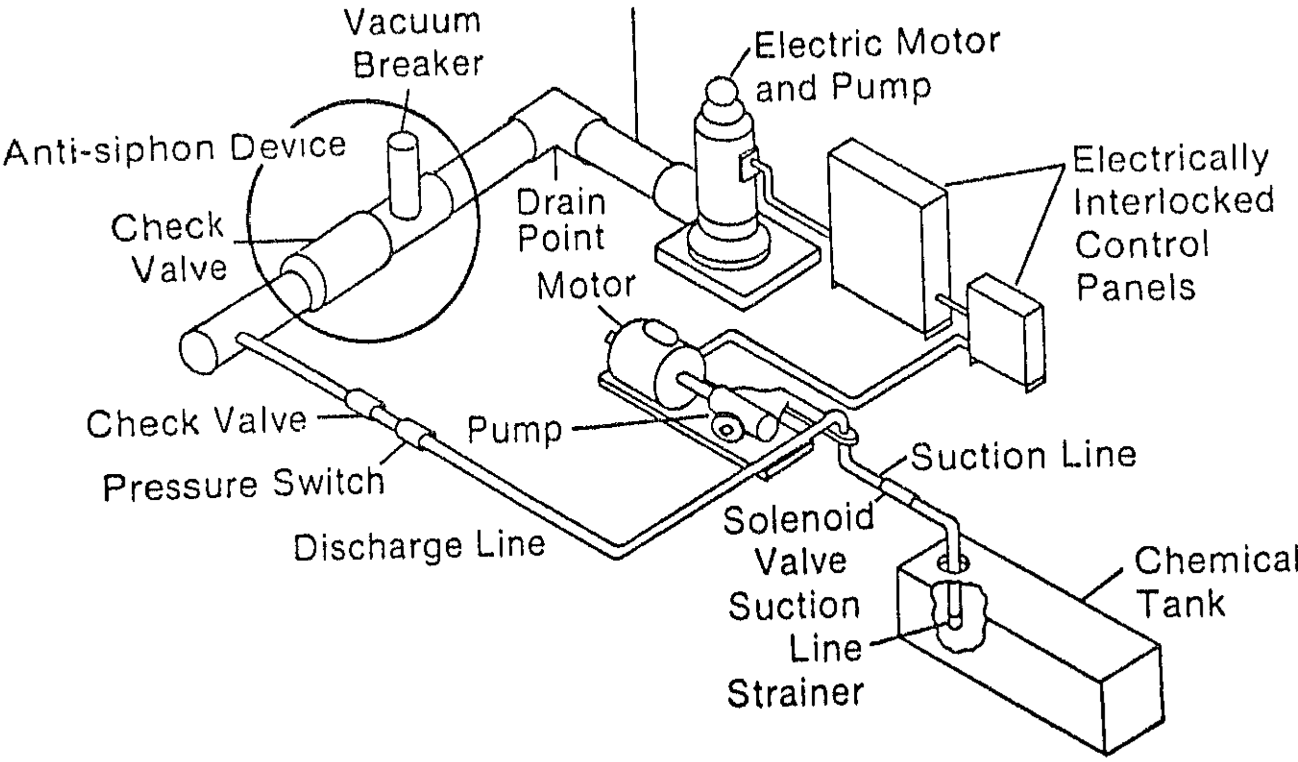


Figure 6-11. Chemigation safety equipment for electric motor irrigation pumping plant.

manual gate valve, ball valve, or a "normally off" solenoid valve. This valve must be installed near the bulk chemical storage tank. It must be open only when the injector pump is operating. It must be constructed of materials resistant to chemical corrosion. A disadvantage of the solenoid valve is that corrosive chemicals may cause the valve to fail to operate after only a short period of time. A PVC ball valve will be less affected by corrosion. However, it will require manual operation.

7. Chemical storage tanks must be located remote from the well site or surface water supply. Tanks should be located at a site sufficiently remote and sloped so that contamination of the water supply will not occur if the tank ruptures or it a spill occurs while it is being filled.

Chlorine Injection

Chlorine injection into trickle systems is the most effective and inexpensive treatment for bacterial slimes. The chlorine can be introduced at low concentration, 1 ppm, or as slug treatments at intervals as necessary at concentrations of 10 to 20 ppm for only a few minutes at a time. Slug treatments are generally favored. Sodium hyperchlorite or chlorine gas may be used. Sodium hyperchlorite is usually more economical and safer to use.

Filters

Filters are a necessary component of irrigation systems when the water source is not clean enough to allow for proper operation of the system. Filters are usually needed for pumping for channel or reservoirs and for trickle systems.

When water is supplied from a reservoirs, ditch or lake, a series of box screens should surround the intake of the water line to prevent debris, plants and even fish from ending up in the irrigation system. Slotted PVC pipe can often be used as a pump intake screen. The type filter chosen for system design needs to provide the needed capacity and provide for head loss through the filtering process. Manufacturer's information is vital in this design aspect. Pressure gauges installed prior to filtering and following filtering are vital to determine pressure losses and when back washing is needed. Refer to the manufacturer's recommendations.

Sand Filters

Sand filters are classified in many ways, but in general, have the following features:

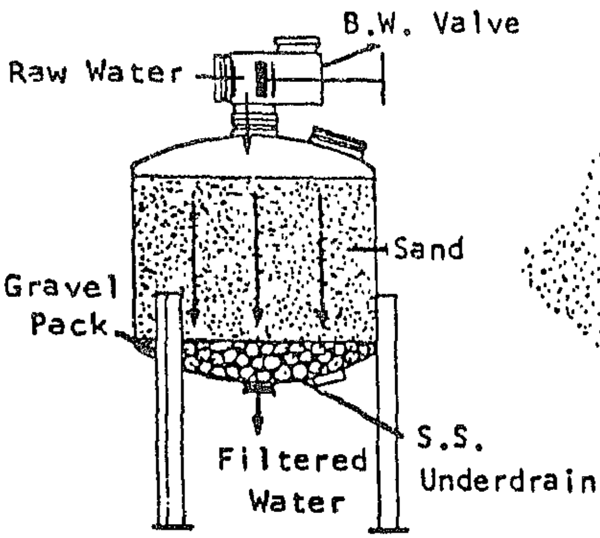
1. Enclosure - to house the filtration media(s) and store the raw water until it is passed through the filtration media(s).

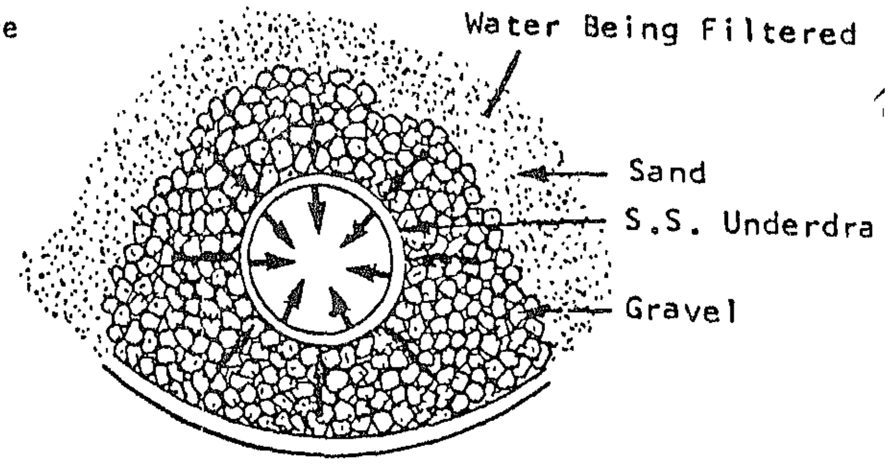
2. Raw water distributor - spread raw water over filtration media.

3. Filtration media - material used to trap the particulate material in the raw water.

4. Underdrain - to collect filtered water and retain filtration media in the enclosure.

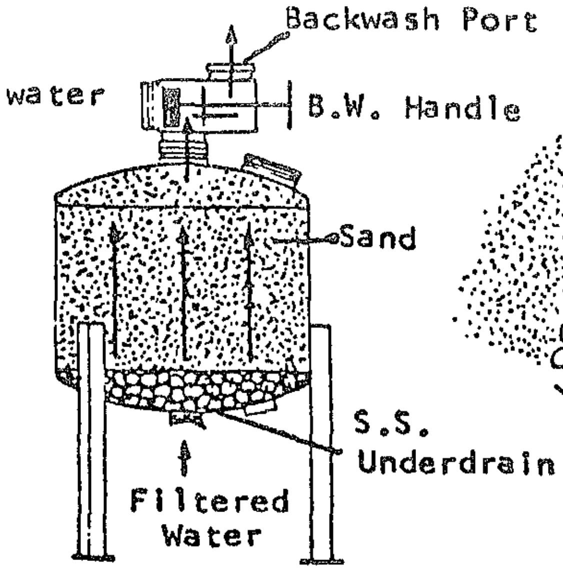
5. Clean out port - removal of filtration medial from the enclosure.

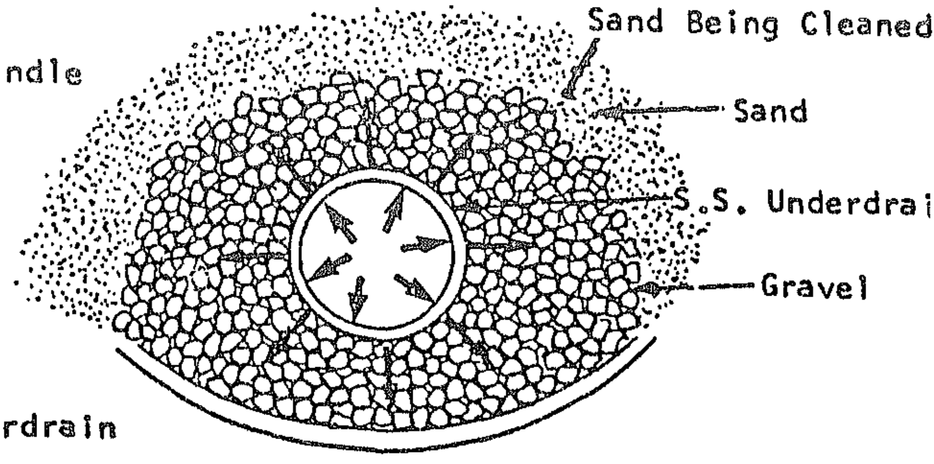




Cross Section

Filtration Operation - Raw water enters filter through the backwash valve, over the water distributor, through the sand bed, deposition of the particulate material, and the filtered water is collected through the stainless steel underdrain and discharged out the bottom.





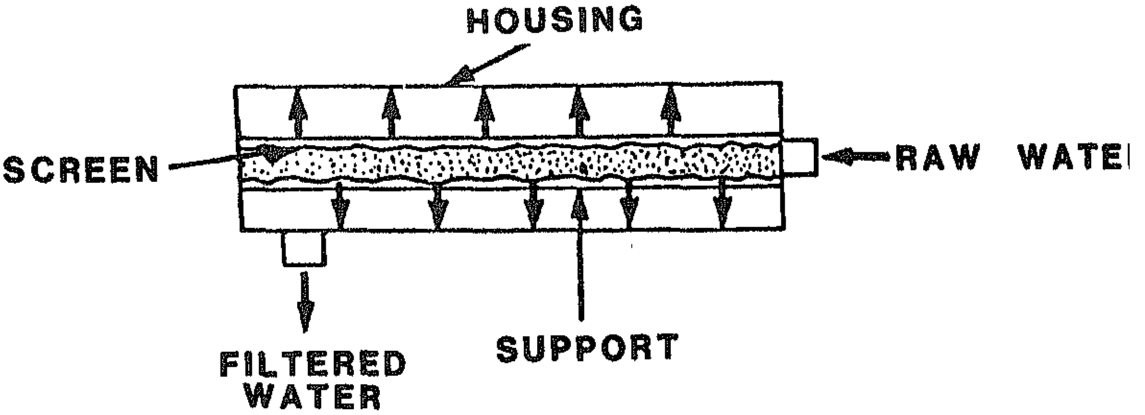
Cross Section

Backwash Operation - The backwash is initiated by screwing the backwash handle forward. This shuts off the incoming raw water and opens the backwash port to a near atmospheric condition. The pressurized filtered water from the adjacent filter(s) is forced through the stainless steel underdrain, upward through the gravel pack, expanding the sand bed and forcing the lighter particulate material out the backwash port and down the backwash line. Screwing the backwash handle in the reverse direction puts the sand filter back into the filtration operation.

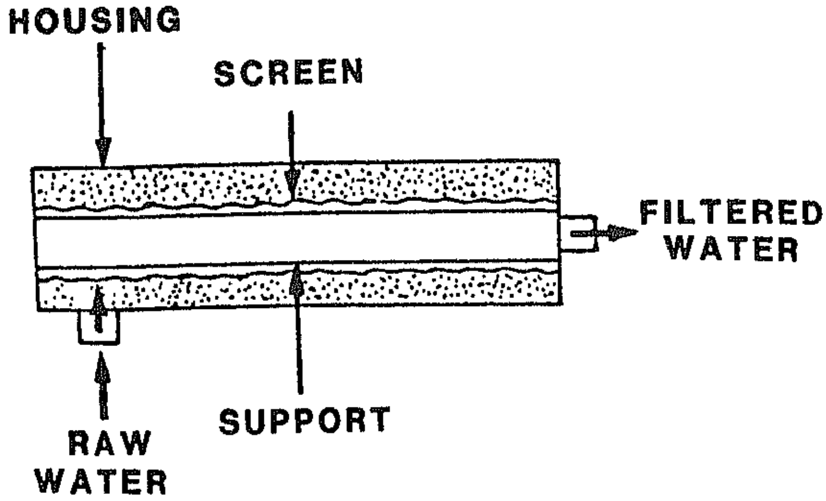
Screen Filters

Screen filters have many different configurations but are basically classified as:

1. Flow from inside out - Raw water enters interior of screen cartridge and filtered water exits along housing body. the support structure for the screen material is the inside of some type cylinder or the cylinder itself is the screen.



2. Flow from outside in - Raw water enters along housing body and through exterior of screen cartridge. Filtered water exits through interior of screen and out the bottom of the housing. The support structure for the screen material is the outside of some type cylinder or the cylinder itself is the screen.



AUTOMATION

Automation is a term applied to processes which reduce or eliminate human labor. A fully automated irrigation system would be one that would sense the crops need for irrigation, turn on and operate the system and turn off the system after the proper amount of water has been applied. Few systems are fully automated, but solid-set and self propelled big gun, boom, lateral move and center pivot sprinkler systems and trickle irrigation systems have reduced human labor requirements for irrigation. Most are manually turned on and operated. Mechanical or electronic controllers can be used to activate automatic valves for automatic operation of the system. The controllers are usually programmed by the irrigator. Moisture sensing equipment that will signal controllers to start and stop irrigation is still in the developmental state.

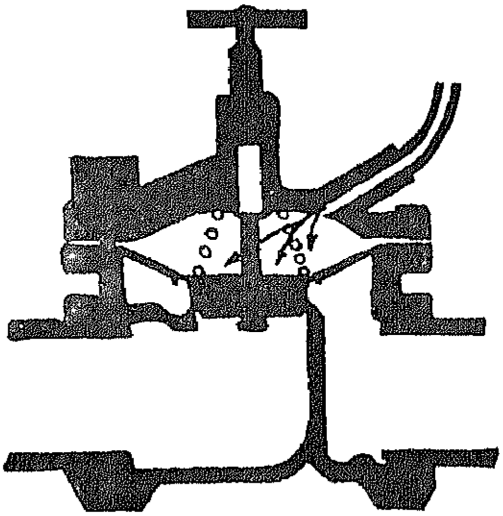
AUTOMATIC VALVES AND CONTROLLERS

This type system provides advantages for many irrigation systems and greatly facilitates proper system management.

The system's operational sequences are programmed into the controller. The controller directs the opening and closing of automatic valves as needed to accomplish the operational sequences. The controller can be mechanical or electrical. The possibility of failure from weather, etc., makes it necessary to have manual operable arrangement as well as having means for quick repairs. Valves are hydraulically or electrically operated.

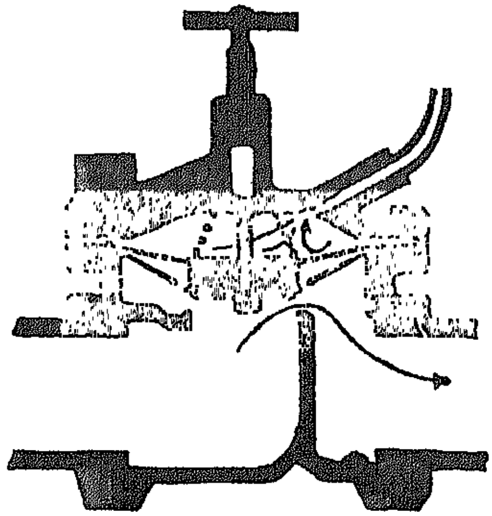
The following sketches explain in greater detail the automatic valve operation.

1. Normally Open Hydraulic - If, with a normally open valve, pressurized water is introduced at the inlet of the valve, the water will pass through the valve when there are no external connections to the valve mechanism. Pressure has to be applied to the inside of the diaphragm or piston of the valve to close it.



CLOSED

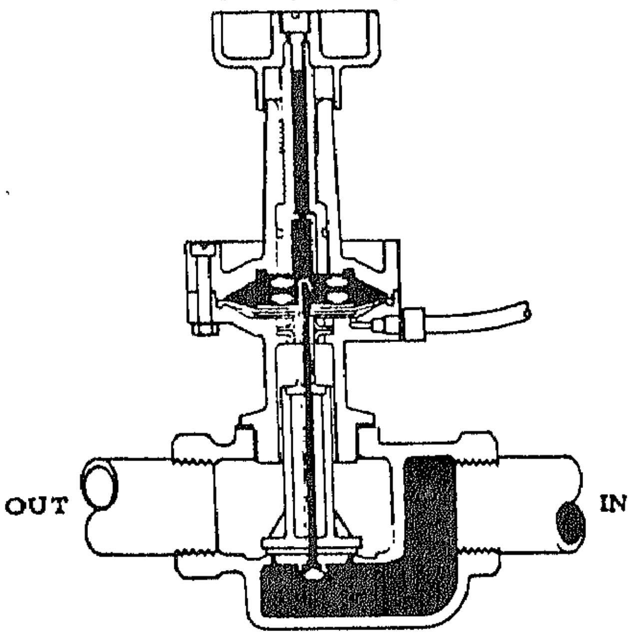
Pressure applied to top of diaphragm from control tubing causes closure of valve. .



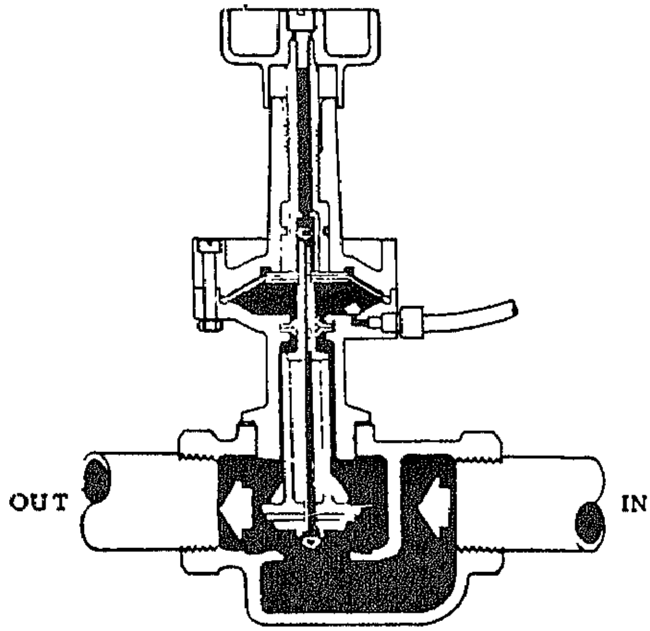
OPEN

Pressure on top of diaphragm is relieved through control tubing allowing valve to open.

2. Normally Closed Hydraulic - If, with a normally closed valve, pressurized water is introduced at the inlet of the valve, the water cannot pass through the valve when there are no external connections to the valve mechanism. Pressure has to be applied to the diaphragm or piston to open the valve.

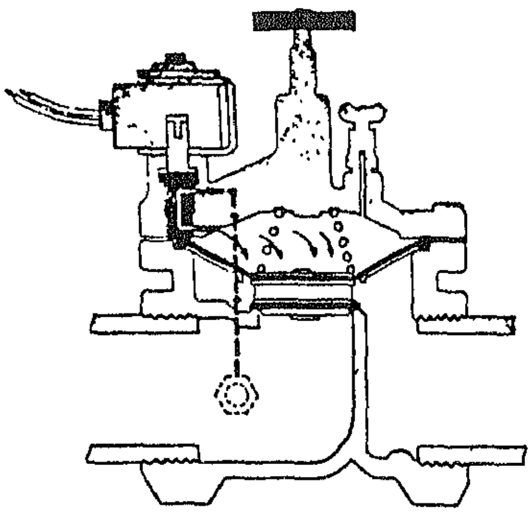


Pressure applied to top side of diaphragm through stem causing closure of valve.



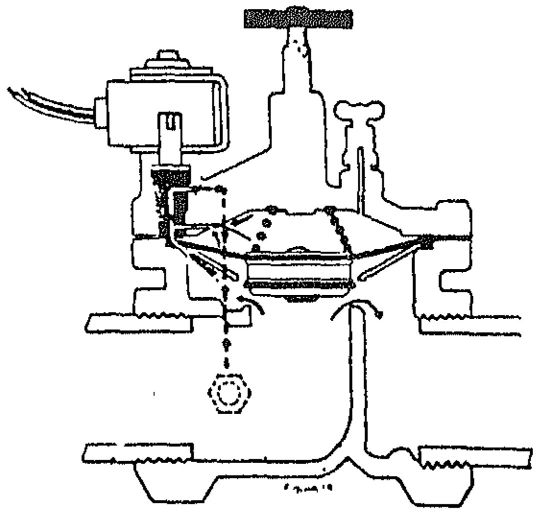
Pressure applied to lower side of diaphragm through control tubing causing water on top side to be displaced through valve and allowing valve to open.

3. Electric - Electric valves are controlled by electric current from the controller, whereas the previously mentioned types are hydraulically controlled by the control mechanism. Electric valves are generally of the normally closed types with current supplied to open the valve. Most electric valves are actually hydraulic valves electrically operated. The current energizes a solenoid which clears a passage for water to flow to or from the diaphragm or piston allowing the valve to open.



CLOSED

Pressure applied to top of diaphragm through screened inlet causes closure of the valve.



OPEN

Pressure on top of diaphragm is relieved through solenoid assembly to downstream side of valve allowing valve to open.

Desirable features on controllers include:

1. Infinite time adjustments on each station. (For precise control of watering time.)

2. No time lag between stations. (To eliminate wasted watering time.)

ant locking cabinet. (To prevent weather and
)

›r up to 14 days is desirable. (To allow the
gramming flexibility.)

and hour programming. (To allow the maximum in
be made quickly and simple.)

6. Sufficient stations on the controller for the area being covered. (Usually a minimum of 11 stations to avoid the requirement of too many controllers.)

7. Pump Circuit. (To enable a controller to kick on the pump starter circuit when the controller begins its watering cycle.)

8. Readability of controls. (To enable the manager to understand and decipher what he needs to know.)

9. Freeze resistance in hydraulic controllers. (To prevent damage due to freezing in areas where the controller mst remain functional even though nighttime temperatures drop below freezing.)

10. U.L. listing. (To qualify for specification on federal, state, and municipal projects.)

11. Manual override switch. (To allow checking of system without disturbing watering program.)

12. Off master switch. (To manually cancel the automatic watering program without disturbing program settings.)

13. Fuse protection of the timing mechanism, electric controllers, the transformer. (To protect against damage to the timing mechanism and transformer in the event of a circuit short.)

14. Easily removable timing mechanism. (So non-field repairs can be made on controller.)

15. Manual operating capability if timing mechanism is removed. (To have continuous operations if timing mechanism is removed for repair.)

16. Filtered supply line on hydraulic controllers. (To protect the pilot valve from plugging.)

Desirable features on valves include:

1. Low friction loss. (To allow pressure to be used in the pipes and sprinklers.)

2. Smooth opening. (To avoid hydraulic ram conditions.)

3. Smooth closing. (To avoid water hammer conditions.)

4. High pressure rating. (To avoid equipment failure at high pressures.)

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 7. CONSERVATION IRRIGATION PLANNING

Contents

CHAPTER 7. CONSERVATION IRRIGATION PLANNING

GENERAL

The material in this section of the Irrigation Guide is intended to help planners assist landowners in planning their irrigation system(s). For more specific information, planners should refer to:

SCS - National Engineering Handbook - Section 15
Chapter 1 - Soil-Plant-Water Relationships
Chapter 3 - Planning Farm Irrigation Systems

DEFINITION OF CONSERVATION IRRIGATION

The use of irrigated soils and irrigation water in a way that insures high production without wasting either water or soil. To an irrigator conservation irrigation can mean saving water, controlling erosion, better crop yields, lower production costs, and continued productivity of his irrigated land.

A conservation irrigation system is the completed arrangement of the delivery and application facilities needed to distribute irrigation water efficiently for all land served by the system.

PLAN REQUIREMENT

An irrigation plan can be divided into two parts:

1. An irrigation system plan which provides for a system of delivery, application and disposal of the water that is consistent with the soil and relief of the land being irrigated and the crops to be grown. The system should apply irrigation water efficiently.

2. An irrigation water management plan which provides for the proper use of water delivered. The document should provide only that data that can be used by the landowner based on his management ability and degree of expertise in irrigation.

IRRIGATION SYSTEM PLAN

The irrigation system plan should provide for the following:

1. The amount and kinds of the crops to be grown, the irrigation requirements of the crops and the expected costs and returns of the system.

2. A water supply that is adequate to meet the requirements of the plan. The supply must be balanced with the irrigation requirements as well as other uses (frost protection, etc.). This may require a water budget.

3. The size and layout of the distribution system needed to supply the water as well as the needed components.

4. The pumping plant requirements to supply the system at the specified rate and pressure.

5. The selected irrigation method capable of applying irrigation water consistent with the soil characteristics and crop requirements.

   a. Subsurface irrigation systems must be capable of moving water to the root zone of the crop at a rate sufficient to supply the plant requirements during peak use periods. Also, it must be capable of draining excess water from the soil profile during periods of high rainfall at a rate sufficient to prevent crop damage due to poor aeration.

   b. In sprinkler irrigation, the sprinkler spacing, nozzle sizes and operating pressure that will most nearly meet the planned application rate and distribution will be used. The main lines, lateral lines, hoses, etc., must be able to supply the water to the sprinklers at the rate and pressure required.

   c. In trickle irrigation the emitters must be capable of providing the peak consumptive use of the crop on a daily basis with a wetted area that will provide good distribution to the root zone. The main lines, submains and lateral lines must be capable of supplying the water to the emitters.

6. Tailwater recovery system when needed for efficient use of water.

7. The necessary practices to remove runoff and excess subsurface water without excessive erosion or other problems.

8. A flow meter or other type of measuring devise that measures the rate of flow and total water use, so the irrigation efficiency and proper water use can be determined quickly.

9. Access to all areas for easy operation of the irrigation system, normal farming operations and removal of crops. This may involve access roads, culverts in ditches, etc.

2. The estimated application rate, irrigation time required and irrigation interval.

3. A method or methods to measure the soil moisture content.

4. A method or methods to determine when to irrigate (irrigation scheduling procedure).

5. A procedure of how to compute the amount of water to apply each irrigation.

6. The soil moisture level when irrigation is needed and priority water needs of crops to be grown.

7. A method of evaluating the uniformity and adequacy of irrigations and suggestions for improvement.

PLANNING STEPS

The planning aspects of irrigation system cannot be over emphasized. A quality irrigation system plan and water management plan does not happen accidentally but comes about through quality planning. Planning can be divided into three phases consisting of (1) preliminary considerations, (2) collecting basic data, and (3) planning the system.

PRELIMINARY CONSIDERATIONS

The major items requiring preliminary considerations are discussed below:

1. Consider the capability of the soil to be irrigated. Irrigation should be confined to land that is capable of sustaining yields high enough for the land user to get a profit from irrigation without soil deterioration.

2. Consider the entire farm unit even if the landowner is interested in only one field. This will make sure that pipelines will be of an adequate size and elevations to service the rest of the land unit. Implementation of the plan will usually begin with one field or one pipeline and normally will continue over a period of time. Revisions will normally be necessary before the entire system is installed.

3. Landowners preference - Each landowner has a preference as to the kind of farm enterprise he wishes, which may dictate the kind of irrigation system and application method. He may have some strong feelings about one system over another. He will operate it much more effectively if he hasn't been pressured into a system. The planner needs to layout the pros and cons including the labor requirements and economic considerations of the "best fit" system.

4. Quantity and Quality of Water - An adequate source of good quality irrigation water must be available or there must be the possibility

of developing an adequate source. If the quantity of water is inadequate during the growing season, there could be crop loss even with an irrigation system. The landowner should be presented with an estimated seasonal water demand and peak use rate of the crop to be grown.

5. Wildlife wetland - locate on map all wildlife wetland in area planned for irrigation, prepare an Environmental Evaluation, and explain SCS policy concerning drainage and alteration of wetlands to land user.

6. Consider that erosion control practices may need to be installed or strengthened to protect the land from more intense use. The erosion control system may need to be modified to prevent interference with the irrigation system.

COLLECTING BASIC DATA

After the preliminary meeting with the landowner and considerations are given to the items discussed above, basic data should be collected. Listed below are basic data that should be obtained.

1. List the following soil and cropping system data:

    a. Soil types and area of each soil type.

    b. Amount and kind of crops to be grown.

    c. Water holding capacity to the depth of root zone of the crops grown.

    d. Intake rate of the soils under the cropping conditions that may occur during irrigation.

    e. Production costs before and after irrigation for crops to be grown.

2. The water supply quantity, quality and location should be determined.

3. Physical features that will affect the system design and location should be placed on the layout map. This includes such items as roads, utility lines, buildings, etc.

4. A complete topographic map may be required but in some areas the following topographic information may be all that is needed:

    a. Expected Low elevation of water supply.

    b. Ground elevation of pump location.

c. Ground elevation of low and high points, along the supply system and the irrigation system.

d. Intake rate of the soils under the cropping conditions that may occur during irrigation.

e. Production costs before and after irrigation for crops to be grown.

5. Locate on map all existing surface and subsurface drainage features such as terraces, waterways, tile drains, ditches, washes, etc., so the irrigation system can be properly planned and cost of making the needed changes to these features can be estimated.

6. Locate on map the needed surface and subsurface drainage practices, such as terraces, waterways, ditches, subsurface drains, etc. This information should be in enough detail to estimate the cost for each needed practice.

7. The location and sizes of the existing system should be checked. It should be determined if it is adequate in part or in whole and how it will fit with the proposed system. The best kind of transition from the present system to the future system should be determined.

PLANNING THE SYSTEM

The actual irrigation system can be planned once the basic data has been collected. Listed below are some steps to follow in planning the system:

1. Decide on the type(s) of systems that will be used. Sprinkler, trickle, subirrigation, etc. Develop alternatives for each practical system.

   Develop and plan field arrangement, consider:

   a. Method of irrigation.

   b. Workability, shape and access to field. Make the field as big and as square as possible.

   c. Direction of irrigation. Would changing the direction of irrigation have any benefits?

2. Prepare the irrigation system plan:

   a. Sprinkler irrigation:

      (1) Determine type of sprinkler system to use: center pivot, single sprinkler, volume gun (manual move or self move), portable or permanent solid set.

(2) Spacing of sprinkler heads on lateral.

(3) Spacing of laterals or lane spacing.

(4) Discharge (gpm) per sprinkler head.

(5) Sprinkler discharge pressure.

(6) Lateral and mainline pressure.

(7) Application rate.

b. Trickle irrigation:

(1) Determine type of trickle irrigation: drip, spray, etc.

(2) Spacing of emitters along lateral

(3) Lateral spacing

(4) Percent of design area covered by emitters

(5) Lateral and mainline pressure

(6) Discharge rate of emitter

c. Subsurface irrigation:

(1) Determine type of subsurface irrigation: open ditches, underground pipes, or combination.

(2) Spacing of ditches and/or pipes.

(3) Number and location of water control structures.

(4) Tail water recovery or disposal.

(5) Number and location of water table measuring structures.

3. Plan the Water Distribution System:

a. Ditch or Pipeline:

(1) Cost of each.

(2) Convenience in farming over pipeline.

(3) Value of land displaced by surface ditch. How much income would be generated if it was in production?

b. Type of turnout to field:

(1) Gated concrete turnout, port, or siphon for ditch.

(2) Alfalfa valve turnout for pipeline can be automated.

c. Measurement of water:

(1) Parshall flume, propeller meter, etc.

(2) Consider totalizer as well as flow meter when possible so total quantity is known.

4. Plan water disposal and/or tailwater resuse system:

a. Tailwater pit size (volume of storage).

b. Pineline if pump back system.

c. Gravity flow to downslope field.

d. Pump size needed - head and capacity.

e. Location of tailwater pump and other structures.

5. Plan farm road system:

a. Access to all parts of the irrigation distribution system for maintenance and operational ease.

b. Access to all fields for planting, tillage, and harvesting operations.

c. All season roads needed? In whole or in part?

d. Don't use bottom of Grass Waterway for road.

6. Plan subsurface drainage system:

a. Size of drains.

b. Depth of drains.

c. Filter material required.

d. Outlet necessary - gravity or pump.

7. Plan erosion control measures - may need mulch left on ground, etc.

a. Erosion control measures should be c irrigation system.

b. Consider use of Water and Sediment C ground outlets when possible.

8. Develop a maintenance program for the following (minimum):

    a. Ditches - maintenance of berms, removal of vegetation when necessary, cleanout of debris and soil from ditch.

    b. Erosion control practices such as terraces, grass waterways, and field boders.

    c. Pipelines and components valves working properly, any leaks?

    d. Turnout structures and measuring devices in proper working order?

    e. Sprinklers - check for wear.

    f. Pumps and motors - Maintenance not performed will cost money because of shutdowns at critical times, lowered efficiency so more fuel use, etc.

    g. Trickle irrigation - check for clogging, make schedule for flushing system out and operating system off-season to reduce emitters clogging.

    h. Schedule a time to perform maintenance. Off-season if possible, preparation for winter, etc.

9. Develop cost guidelines:

    a. Cost per unit and total cost for all alternatives considered.

    b. Cost of energy, i.e., hours system in operation times cost of fuel used per hour.

10. Prepare a development schedule:

    a. Least costly segments with greatest returns first.

    b. How will the new pieces fit in with the existing system, i.e., dirt ditch to pipeline?

11. Consider automation - more automation means more water efficiency and less labor.

12. Prepare a water management plan - specify operating criteria for application of water under varying conditions.

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 8. IRRIGATION ENERGY USE

CONTENTS

Figures

Tables

CHAPTER 8. IRRIGATION ENERGY USE

GENERAL

With the high costs of energy, it is important that the irrigator examine every aspect of the irrigation system and seek ways to optimize energy use. It is possible to combine energy conservation techniques and good irrigation management practices to conserve both water and energy.

PUMPING PLANT EFFICIENCY

The pumping plant should be designed to deliver the water as economically as possible and is one area of the irrigation system where needed improvements in operating efficiency can be made relatively easy. Proper repair of a formerly efficient component, or proper selection of a replacement for an inefficient component, can bring efficiency up to the desired level.

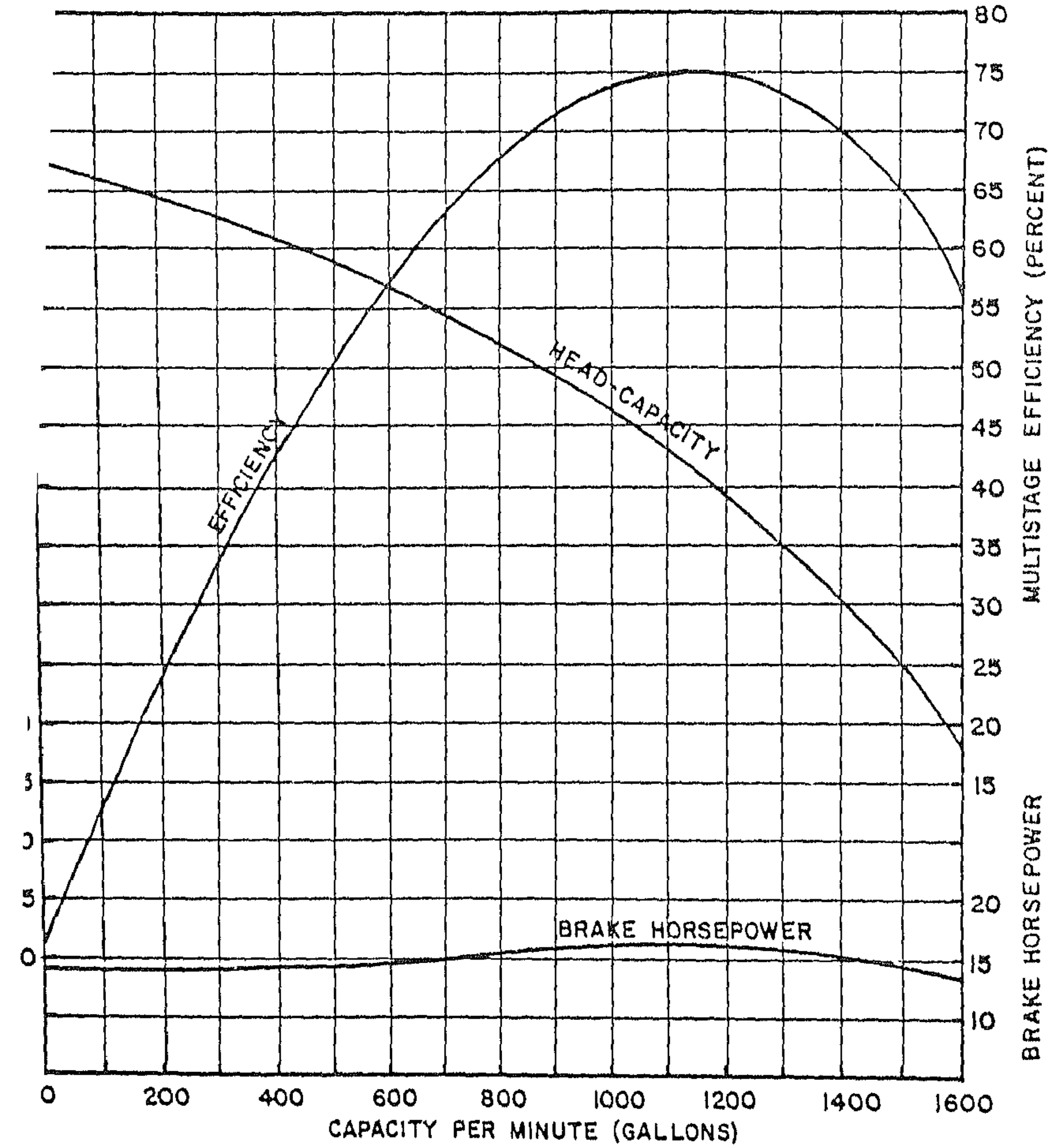
A pumping plant consists of three components - a pump, a power unit and a drive assembly. Drive assemblies will be discussed first. Direct drive assemblies - hollow-shaft motors, flexible couplings and tabular drive shafts - are 100 percent efficient in transmitting power. Nothing can be done to improve their power transmission efficiency. Belt drives are not 100 percent efficient. Pulley diameter, distance between pulley centers and belt tension, all affect belt life and power transmission efficiency. Properly designed, installed and maintained V-belt drives are capable of 95-97 percent efficiency while flat belt drives are capable of transmitting 80-90 percent of the power from the drive to the driven unit. Ninety (90) degree gear drives are 95 percent efficient.

Pump assemblies is one area where proper design and selection can really pay. One factor must be kept in mind. Each particular model/size of pump has its own operating characteristics. See Figure 8-1 showing a typical operating curve. The operating efficiency of a pump depends upon the combination of gallons per minute, discharge pressure and pump speed. A properly selected pump will have a high operating efficiency while delivering the desired combination of gpm and pressure. The most efficient combination of discharge and pressure varies with changes in pump speed. Changes in either pumping lift, discharge pressure or well yield also affect pumping efficiency.

The power unit is easier to maintain in top efficiency than the pump since it is readily visible and available to repair. Electric motors, especially three-phase units, are inherently quite efficient in converting electrical energy into mechanical motion. Internal combustion engines vary considerably in their ability to convert petroleum fuel into mechanical motion. Proper maintenance does much toward keeping the engine operating efficiently. Many irrigation engines have been selected on the basis of low initial cost. This has frequently resulted in a smaller engine being operated at its upper limits of revolutions per minute which not only shortens engine life but

Figure 8-1

PERFORMANCE CURVES OF A DEEP-WELL TURBINE OF THE MIXED-FLOW TYPE, SPEED 1,750 r.p.m.



$$\text{WATER HORSEPOWER} = \frac{Q(\text{gpm}) \cdot H(\text{ft})}{3960}$$

$$\text{BRAKE HORSEPOWER} = \frac{Q(\text{gpm}) \cdot H(\text{ft})}{3960 \cdot \text{efficiency}}$$

$$\text{MP EFFICIENCY} = \frac{\text{Output (Water) Horsepower}}{\text{Input (Brake) Horsepower}} \times 100\%$$

frequently increases the amount of fuel consumed per horsepower-hour of output. Manufacturers provide performance data on their engines which includes a curve showing the "amount of fuel per horsepower-hour" output by the engine at various speeds. See Figure 8-2 showing typical performance curves. Considering fuel consumption per horsepower-hour as well as initial price can be profitable.

PUMPING PLANT ENERGY REQUIREMENTS

There are three factors that determine the power and energy requirements of an irrigation pumping plant. They are:

1. The quantity of water being pumped expressed as gallons per minute (gpm).

2. The total dynamic head (TDH) expressed in feet.

3. The efficiency of the pump expressed as a decimal.

The useful work done by a pump or the water horsepower (whp) required is expressed by the formula:

$$\text{whp} = \frac{\text{gpm} \times \text{TDH}}{3960}$$

The water horsepower represents the power that would be required to operate the pump if the pump and drive were 100-percent efficient.

The brake horsepower (bhp) required to operate a pump is determined by the formula:

$$\text{bhp} = \frac{\text{whp}}{\text{pump efficiency} \times \text{drive efficiency}}$$

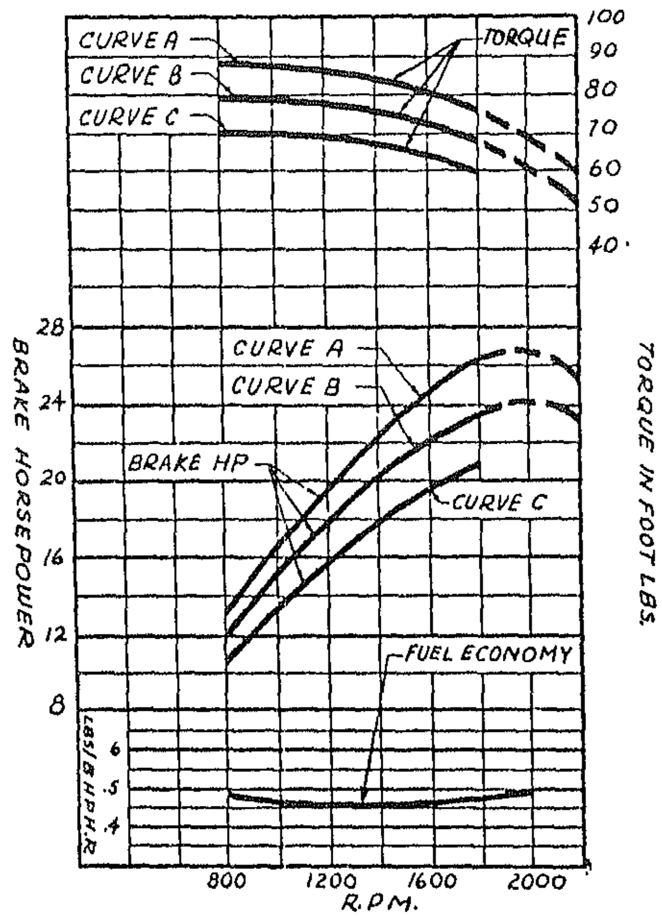
The horsepower requirement of the power unit is expressed by the following formula:

$$\text{Size of engine or motor} = \frac{\text{bhp}}{\text{efficiency of power unit}}$$

Inefficient irrigation pumping systems waste fuel and increase the cost per unit of water delivered. As fuel and electrical power costs increase, the cost of operating an inefficient pump increases even more.

Efficiency of a pumping system is defined as a ratio of the work being done by the system to the power or energy being supplied to it. Pump efficiency can be expressed as:

$$\frac{\text{output}}{\text{input}} = \frac{\text{whp}}{\text{bhp}}$$



Performance Curve of "166" Diesel Unit.

rve A: Maximum performance.
rve B: Maximum permissible for intermittent service.
rve C: Maximum permissible for continuous service.

uipment included: 4-blade fan, oil-bath air cleaner, ffler and generator.

:e 8-2. Typical Engine Performance Curve

ENERGY FACTS

Table 8-1 presents performance standards for both power units and pumping plants. Power unit performance standards are given in terms of power produced (in horsepower-hours, hp-hr) per unit of fuel consumed (in gallons, gal or kilowatt-hours, kwh). These figures represent the efficiency of a typical power unit in converting fuel or electrical power to mechanical. Note the efficiency of a power unit (pumping plant) in this situation is a percent of the standard rather than a ratio of energy in (fuel) to energy out (whp). Pumping plant performance standards are given in water horsepower-hours (whp-hr) per gal or kwh. They include allowances for normal pump efficiencies, drive losses, and friction losses in the discharge column and discharge head. Pumping system performance standards are expressed in terms of units of fuel consumed because they can be easily measured, whereas mechanical power input to a pump can be measured only with specialized instrumentation.

Table 8-1

Nebraska Performance Standards for Irrigation Pumping Plants

Fuel	Power Unit Performance Standards	Pumping Plant* Performance Standards
Diesel	14.58 hp-hr/gal	10.94 whp-hr/gal
Gasoline	11.30 hp-hr/gal	8.48 whp-hr/gal
Propane (LP-gas)	9.20 hp-hr/gal	6.89 whp-hr/gal
Natural Gas	88.93 hp-hr/1000 cu ft	66.70 whp-hr/1000 cu ft
Electricity	1.18 hp-hr/kwh	0.885 whp-hr/kwh

*Based on 75% pump efficiency. Figures do not include drive assembly losses.

From Table 8-1, it is readily seen that diesel fuel is the most efficient of the liquid fuels. However, the initial cost of a diesel power unit is usually considerably greater than that of other internal combustion engines.

PUMPING PLANT PERFORMANCE

A pumping performance test requires that the physical properties that determine pumping plant efficiency be measured. Pumping rate, pumping lift, pressure at the discharge outlet, and the amount of fuel consumed over a period of time must be measured while the pump is operating at its normal load. The engine and pump speed should also be measured to ensure that the manufacturer's recommendations are being followed.

CALCULATING PUMPING PLANT EFFICIENCY

An example set of field data is presented to illustrate the procedure for calculation of pumping plant efficiency:

Pump Discharge Rate, Q = 600 gpm
Pumping Lift, Le = 70 ft
Discharge Pressure, P = 60 psi
Pump Speed = 1750 rpm
Fuel Consumed (Diesel) = 4.0 gal
Pump Test Duration = 1.0 hr

1. Check Pump Speed:

   Pump should be measured with a portable tachometer to assure that the pump is being operated according to its specifications. The design pump operating speed should be stamped on a plate attached to the pump discharge head.

   In this example, the measured pump speed (1750 rpm) was found to be very nearly the required pump operating speed (1760 rpm). If it were not, speed must be adjusted before continuing.

2. Calculate Total Dynamic Head (TDH):

   TDH = Pumping Lift (ft) + Discharge Pressure (ft)
   TDH = 70 ft + (60 psi x 2.31 ft/psi)
   TDH = 70 ft + 139 ft = 209 ft

3. Calculate Water (Output) Horsepower, whp:

   $$\text{whp} = \frac{Q \times H}{3960}$$

   $$\text{whp} = \frac{600 \text{ gpm} \times 209 \text{ ft}}{3960}$$

   whp = 31.7 hp

4. Calculate Pumping Plant Performance:

   $$\text{Performance (whp - hr/gal)} = \frac{\text{whp} \times \text{Test Duration (hr)}}{\text{Fuel Consumed (gal)}}$$

   $$\text{Performance} = \frac{31.7 \text{ hp} \times 1.0 \text{ hr}}{4.0 \text{ gal}}$$

   Performance = 7.9 whp - hr/gal

5. Calculate Pumping Plant Efficiency, Eff

   $$\text{Eff} = \frac{\text{Pumping Plant Performance}}{\text{Performance Standard}} \times 100\%$$

   $$\text{Eff} = \frac{7.9 \text{ whp - hr/gal}}{10.94 \text{ whp - hr/gal}} \times 100\%$$

   Eff = 72.2%

6. Calculate Fuel Wasted per Hour:

Fuel Wasted/Hour = Current Fuel Consumption Rate x (1-Eff)

Fuel Wasted/Hour = 4.0 gal/hr x (1-0.722)

Fuel Wasted/Hour = 1.1 gal/hr

In this example, the actual pumping plant performance of 7.9 whp-hr/gal is only 72.2 percent of the performance standard for diesel powered pumping plants. For the size of unit described, 1.1 gal/hr of diesel fuel is wasted because the pumping plant is not operating efficiently in its current condition. Whether or not this loss in efficiency is significant enough to justify having the pumping unit repaired depends upon the expected repair cost and the number of hours of pump operation per year. In general, if the repair cost can be regained by savings in operating costs over a 2-3 year period of time, then it will be economically feasible to have the repairs made. The actual repayment time can only be calculated using a detailed economic analysis including the expected efficiency increases, fuel cost, and the repair costs amortized over the period of time.

CAUSES FOR SUBSTANDARD PUMP PERFORMANCE

Substandard performance in the pump can be caused by several factors. The pump could be mismatched for present conditions. The pump may not have been properly selected or the operarting conditions may have changed. The water table could have dropped or a new pipeline could have changed the pumping head requirement. The power source may not be operating at the specified speed (rpm) for maximum efficiency.

The impellers could be out of adjustment. Qualified repairment can adjust the impeller clearance with the bowl for the greatest efficiency. If the impeller is badly worn or corroded, adjustment will not help. Cavitation occurs in pumps that attempt to operate at flow rates greater than the well can supply. This pits the impellers and ruins them.

Poorly designed pumping systems would result in low efficiency ratings. This could be caused by such factors as an undersized suction pipe, restrictions in the intake strainer, or improperly sized discharge column. Misalignment of the drive shaft also decreases efficiency. Excessive wear is a sign of this.

ENERGY COSTS

Table 8-2 shows the cost per hour pumping for various fuels, fuel costs and horsepower loads. These will serve as valuable information in planning irrigation systems.

Figure 8-3 compares the cost of diesel, propane, and gasoline to the cost of electricity.

METHODS OF REDUCING ENERGY REQUIREMENTS

Proper selection, operation, maintenance and management of an irrigation system to fit the soil type and cropping system can save much energy. In the selection of an irrigation system, the system's energy costs should be considered as well as its initial costs. Sprinkler irrigation systems vary in the energy requirements. Single sprinkler volume guns are high energy users, permanent/solid-set systems are medium energy users and center pivot systems range from medium to low energy users. Subirrigation systems using furrows, ditches or pipes are relatively low energy users as well as trickle irrigation systems. Ways to save energy are discussed below.

INCREASING PUMPING PLANT EFFICIENCY

As was shown in the example on page 8-7, much energy can be saved by increasing the efficiency of the pumping plant. An irrigation pumping plant efficiency testing program was recently initiated in Georgia. Measured efficiencies have ranged from 12 percent to 119 percent and averaged 63 percent. This represents an average monetary loss of 37 cents per dollar of fuel cost and a potential energy savings of up to 9 million gallons of diesel fuel annually in Georgia if system efficiencies were increased to optimum levels.

REDUCING OPERATING PRESSURE

Table 8-2. IRRIGATION POWER AND FUEL COST COMPARISON CHART

A - ELECTRICITY - Cost/hour of pumping (Based on 1.18 hp-hr/KWH*)

Pump Load HP	Rates per kilowatt-hour 4¢	5¢	6¢	7¢	8¢	9¢
10	$0.34	$0.42	$0.51	$0.59	$0.68	$0.76
20	0.68	0.85	1.02	1.19	1.36	1.53
30	1.02	1.27	1.53	1.78	2.03	2.29
40	1.36	1.69	2.03	2.37	2.71	3.05
50	1.69	2.12	2.54	2.97	3.39	3.81
75	2.54	3.18	3.81	4.45	5.08	5.72
100	3.39	4.24	5.08	5.93	6.78	7.63

B - DIESEL - Cost/hour of pumping (Based on 14.58 hp-hr/gal*)

Pump Load HP	Fuel cost per gallon $1.00	$1.10	$1.20	$1.30	$1.40	$1.50
10	$0.69	$0.75	$0.82	$0.89	$0.96	$1.03
20	1.37	1.51	1.65	1.78	1.92	2.06
30	2.06	2.26	2.47	2.67	2.88	3.09
40	2.74	3.02	3.29	3.57	3.84	4.12
50	3.43	3.77	4.12	4.46	4.80	5.14
75	5.14	5.66	6.17	6.69	7.20	7.72
100	6.86	7.54	8.23	8.92	9.60	10.29

C - GASOLINE - Cost/hour of pumping (Based on 11.30 hp-hr/gal*)

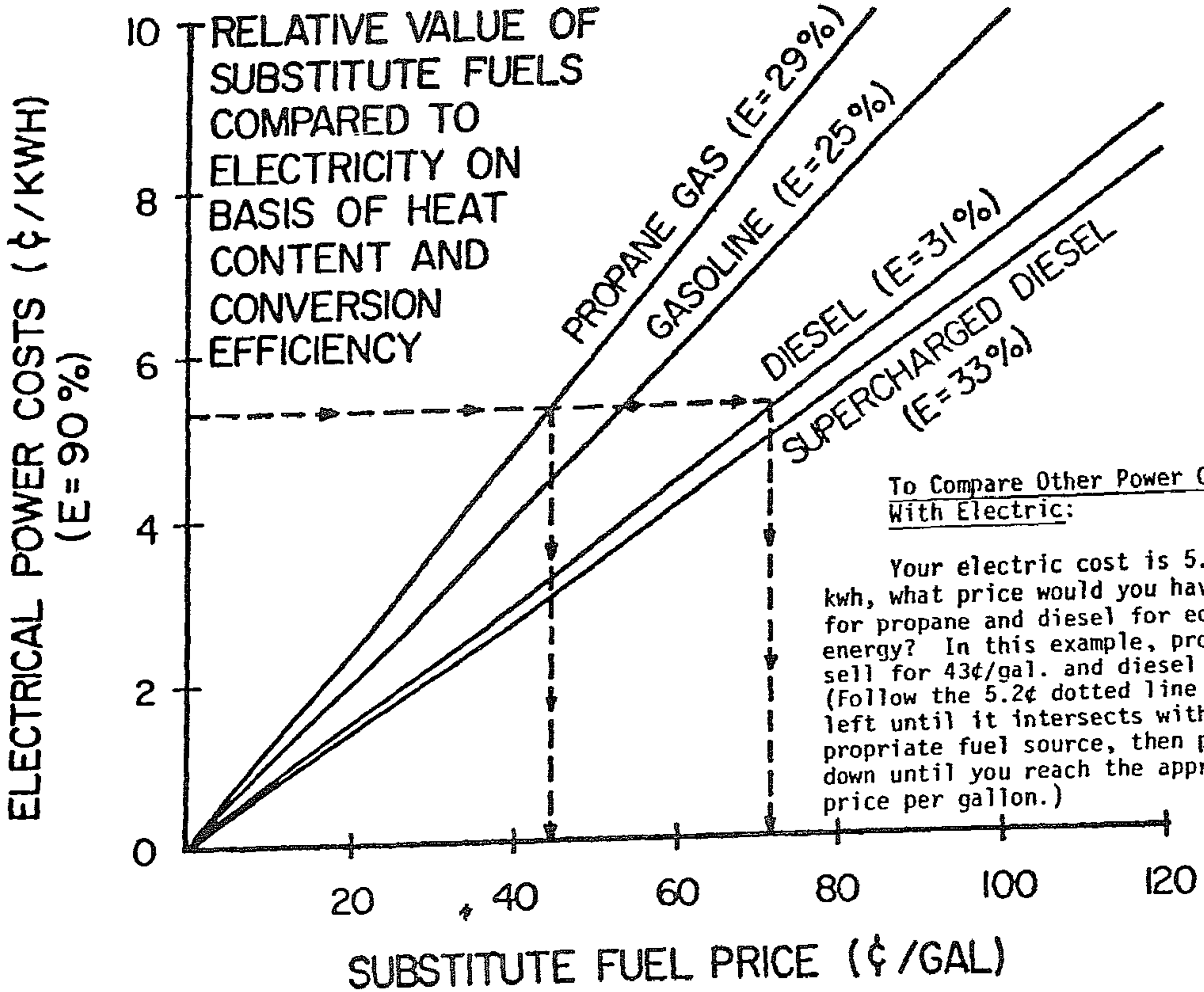
Pump Load HP	Fuel cost per gallon $1.00	$1.10	$1.20	$1.30	$1.40	$1.50
10	$0.88	$0.97	$1.06	$1.15	$1.24	$1.33
20	1.77	1.95	2.12	2.30	2.48	2.65
30	2.65	2.92	3.19	3.45	3.72	3.98
40	3.54	3.89	4.25	4.60	4.96	5.31
50	4.42	4.87	5.31	5.75	6.19	6.64
75	6.64	7.30	7.96	8.63	9.29	9.96
100	8.85	9.73	10.62	11.50	12.39	13.27

D - PROPANE - Cost/hour of pumping (Based on 9.2 hp-hr/gal*)

Pump Load HP	Fuel cost per gallon $0.80	$0.90	$1.00	$1.10	$1.20	$1.30
10	$0.87	$0.98	$1.09	$1.20	$1.30	$1.41
20	1.74	1.96	2.17	2.39	2.61	2.83
30	2.61	2.93	3.26	3.59	3.91	4.24
40	3.48	3.91	4.35	4.78	5.22	5.65
50	4.35	4.89	5.43	5.98	6.52	7.07
75	6.52	7.34	8.15	8.97	9.78	10.60
100	8.70	9.78	10.87	11.96	13.04	14.13

*Nebraska Standards for Engine Performance considered attainable in practice. Of 376 pumping plants tested in Nebraska 1956-62, only 33 or 8.8% exceeded the standard, 59% met or exceeded 75% of the standard. Efficiency of internal combustion engines can be expected to drop in normal use. Electric motor efficiency should change very little.

NOTE: All costs per hour are rounded to the nearest cent. Costs are for Fuel or power only, no lubrication, repairs, etc. Must divide by pump and drive efficiency to get actual cost/hour.



To Compare Other Power Costs With Electric:

Your electric cost is 5.2¢ per kwh, what price would you have to pay for propane and diesel for equivalent energy? In this example, propane must sell for 43¢/gal. and diesel for 70¢. (Follow the 5.2¢ dotted line on the left until it intersects with the appropriate fuel source, then proceed down until you reach the appropriate price per gallon.)

NOTE: This graph presents fuel costs only, and not associated changes such as electric power standby or demand costs.

Figure 8-3

$$\text{30 psi system, whp} = \frac{(800\text{ gpm})\ (30\text{ psi} \times 2.31\text{ ft/psi})}{3960} = 14.0$$

The savings of using the 30 psi system over the 80 psi system would be 23.3 whp (37.3 whp - 14.0 whp).

From Table 8-1, for a diesel unit the fuel savings would be:

23.3 whp - 10.94 whp - hr/gal = 2.1 gal/hr

Using a diesel price of $1.15/gal, then the savings would be:

2.1 gal/hr x $1.15 gal = $2.42/hr

If the system is operated 500 hours per year, then the annual fuel savings would be:

500 hrs x $2.42/hr = $<u>1,210</u>

or

2.1 gal/hr x 500 hrs = <u>1050 gal of fuel</u>

Some farmers are converting from high pressure systems to low pressure systems. It should be understood that converting to low pressure systems will reduce pumping costs only if the pumping plant is designed for low pressure. Most pumps are set to deliver a given gpm at a given head to get the maximum efficiency of the pumping plant. When this head is reduced, the gpm will increase. This usually results in a lower efficiency for the pumping plant, with the consequent higher energy use for pumping an acre inch of water.

Converting high pressure center pivot to low pressure center pivot reduces the wetted diameter of the sprinklers on the order of $\pm$100 feet to 40 to 60 feet. So the same amount of water would be put on a strip about half as wide with low pressure center pivots. Therefore, the application rate of water is about twice as much in inches per hour. this can cause serious runoff on the heavier soils especially where there are sloping areas. This should be given consideration when deciding on converting center pivot systems from high pressure to low pressure.

SIZING OF IRRIGATION PIPELINE

The friction loss in a pipeline increases, approximately, in proportion to the square of the water velocity in the pipeline.

Water Velocity ft/sec	Square
1	1
2	4
3	9
4	16
5	25

Consider friction loss to be comparable to energy use. The higher the friction loss the more energy that is required to pump water through a pipeline.

Compare the three foot per second velocity to the four foot per second velocity in the table above. This compares three squared which equals nine to four squared which equals sixteen. Sixteen divided by nine equals 1.78. Friction loss at a velocity of four feet per second is approximately 1.78 times the friction loss at three feet per second.

It is considered advantageous to keep pipeline velocities between three and four per second considering initial cost of the material, installation costs and operating costs.

Obviously, on very short pipelines or irrigation systems using gravity flow it may not be advantageous to keep the velocities low because there would be very little savings in operational costs. In this case, five feet per second velocities are considered a maximum to prevent problems connected with surge, water hammer and air entrapment.

On very long pipelines, it may be advantageous to reduce the pipeline velocity to as little as two feet per second thus reducing energy use. Initial material and installation costs should be studied and compared to operating costs to determine the most economical pipe size to be installed. The biggest cost in installing larger pipes is the increased cost of material. Trenching, backfilling, and labor costs usually increase very little when a pipe diameter is increased one size. Velocities should not be dropped below two feet per second unless special studies are made of potential sediment problems.

Example of sizing a pipeline based on energy use and annual pipe cost.

Reference: Appendix C, Friction loss characteristics P.V.C. Class 125.

e. SDR 32.5

per minute

3000 feet

operating time = 1000 hours per year

electricity cost = 5 cents per kw-hr/hr

diesel fuel cost = $1.10 per gallon

total dynamic head = 100 feet + friction loss in pipeline

Pipeline Friction Loss

Pipe Size (Dia)	Velocity (ft/sec)	Friction Loss		Friction Loss in 3000 feet
		psi/100 ft	ft head/100 ft	
8 in	6.22	0.58	1.34	40 ft
10 in	4.00	0.20	0.46	14 ft
12 in	2.84	0.09	0.21	6 ft

It should be noted to begin with that the 8 inch diameter pipeline should not be used because of velocities exceeding 5 ft/sec. This could cause water hammer, surge, or air entrapment problems. The 8 inch size is being shown in the example to illustrate the extra cost associated with higher velocities.

Cost of Electricity

Pipe Size (Dia)	Total Head Loss	whp	whp-hr per kwh	kw-hr per hr	Cost/hr @$0.05/kwh	Cost per 1000 hrs
8 in	140	35	0.885	40	$2.00	$2000
10 in	114	29	0.885	33	1.65	1650
12 in	106	27	0.885	30	1.50	1500

Cost of Diesel

Pipe Size (Dia)	Total Head Loss	whp	whp-hr per gal	gal per hr	Cost/hr @$0.80/gal.	Cost per 1000 hrs
8 in	140	35	10.94	3.2	$2.56	$2560
10 in	114	29	10.94	2.7	2.16	2160
12 in	106	27	10.94	2.5	2.00	2000

The annual amortized pipe cost using the following conditions are:

Pipe Size (Dia.)	Initial Cost	Life (Yrs)	Interest Rate	Annual Amortized Cost
8 in	$11,640	25	12%	$1484.
10 in	$16,500	25	12%	$2104.
12 in	$22,050	25	12%	$2811.

The most economical pipe size would be the one that has the lowest total cost considering both the annual amortized cost and the energy cost as follows:

Pipe Size (Dia.)	Annual Amortized Cost	Annual Energy Cost	Total Cost
	Electric		
8	$1484.	$2000	$3484
10	2104.	1650	3754
12	2811.	1500	4311
	Diesel		
8	$1484	$2560	$4044
10	2104	2160	4264
12	2811	2000	4811

The most economical pipe would be the eight inch size with the ten inch being the next choice. Due to possible water hammer and surge problems with the eight inch size, the ten inch pipe would be the recommended size.

SCHEDULING WATER APPLICATIONS

Probably the one place where energy savings can be affected the quickest is to use management practices which obtain the optimum

$$\text{fuel saved} = 100 \text{ acres} \times \frac{1 \text{ ac-in}}{\text{ac}} \times \frac{27{,}154 \text{ gal}}{\text{ac-in}} \times \frac{1 \text{ min}}{800 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{2.1 \text{ gal}}{\text{hr}}$$

$$= 118.8 \text{ gal of diesel fuel}$$

INCREASING APPLICATION EFFICIENCY

Increasing the application efficiency of the irrigation system will directly save water and energy. This can be done by selecting a system of known high efficiency, designing and laying out the particular system to obtain the most efficiency application possible or irrigate at times when the efficiency would be greater. The example below will illustrate how increasing the application efficiency will save energy.

Assume the system previously discussed with 70 percent application efficiency and an 80 percent application efficiency. If the next irrigation requirement is 1 inch then the gross irrigation requirement for the two efficiencies are:

70 percent = 1.00 inch ÷ 0.70 = 1.43 inches gross application
80 percent = 1.00 inch ÷ 0.80 = 1.25 inches gross application

fuel used at 70% eff. of application

$$= 100 \text{ acres} \times \frac{1.43 \text{ ac-in}}{\text{ac}} \times \frac{27{,}154 \text{ gal}}{\text{ac-in}} \times \frac{1 \text{ min}}{800 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{2.1 \text{ gal}}{\text{hr}}$$

$$= 169.9 \text{ gal}$$

fuel used at 80% eff. of application

$$= 100 \text{ acres} \times \frac{1.25 \text{ ac-in}}{\text{ac}} \times \frac{27{,}154 \text{ gal}}{\text{ac-in}} \times \frac{1 \text{ min}}{800 \text{ gal}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{2.1 \text{ gal}}{\text{hr}}$$

$$= 148.5 \text{ gal}$$

The fuel saved per 1-inch net applications is 21.4 gal (169.9 gal - 148.5 gal). If six 1-inch net applications are required in one season, then 128.4 gallons of fuel could be saved.

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 9. IRRIGATION ECONOMIC EVALUATION

Contents

Tables

Exhibits-Cost and Return

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 9. IRRIGATION ECONOMIC EVALUATION

GENERAL

The proper use of economic tools and procedures will provide cost and return information for alternative courses of action. With adequate economic data, an individual can make a reasonable decision as to the resource management system that best fits his requirements.

In advising farmers on the merits of one irrigation system versus another, or on the question of whether or not to invest in irrigation equipment, it must be remembered that in many instances, factors enter into the decision-making process that cannot be explained in a simple cost-return analysis. In some cases, such considerations as investment tax credit or other tax incentives may strongly influence the decision. If the farmer is financially secure, personal preference may guide his thinking. Another example is a situation where the grower considers an irrigation system to be justifiable in order to protect against the complete loss of a crop during an extremely dry season or for freeze protection but where the average annual benefit may not justify the purchase of a system.

If the farmstead is located in a remote area, an available irrigation system could be used to suppply water for fire suppression. Just the availability of a large, dependable supply of water could provide a sense of security for the farm family.

The above-mentioned reasons for, or advantages of, owning an irrigation system may at least complement the primary purpose for investing in the system which is to increase farm net income. Procedures outlined in this chapter should be useful in analyzing not only whether or not to irrigate, but which system would be most profitable.

DETERMINING IRRIGATION COST AND RETURN ON INVESTMENT

This chapter provides information and methods for determing how much an irrigation system will cost and how to estimate the return on investment. In the final analysis, comparison is made of the average annual cost of irrigating to the value of the estimated annual increase in production. This return on investment may be the deciding factor as to whether to invest in an irrigation system.

As an aid in better understanding the mechanics of calculating irrigation costs and returns, an example is presented and the steps are given for developing cost and return data for a typical irrigation system.

COMPILING INFORMATION NEEDED

To develope cost and return data for an irrigation system, certain information has to be obtained. Exhibit 9-1, General Information, can be used to compile information. The information entered in Exhibit 9-1 will be used as the example in the following sections.

General Information	
Item	Information Needed
1. Crop(s) to be irrigated	Corn
2. Expected increase in yield per acre from irrigation	75 bu
3. Value of crop per unit (pounds, bushels, tons, etc.)	$3.00/bu
4. Maximum soil water- intake-rate	2.6 in/hr
5. Seasonal consumptive use of the crop	21 in
6. Peak-use rate of the crop	0.33 in/day
7. Number of hours to operate per day	22
8. Minimum days required for each irrigation	2.7
9. Number of irrigations expected per season	9
10. Number of hours operation per year	486
11. Shape and dimensions of field	2640' x 2640'
12. Number of acres in field	160
13. Type of system	Center-Pivot
14. Number of acres to be irrigated	126
15. Pumping rate needed in gpm	1200
16. Source of water	Well
17. Total height water is to be lifted	55'
18. Total operating head	170'
19. Size of power unit needed	100 bhp
20. Type of power unit	Diesel
21. Interest rate	15%
22. Stand-by charges for electricity	Not Applicable
23. Hours labor per acre per irrigation	0.05

Exhibit 9-1 General Information

INITIAL COST

When purchasing an irrigation system, one of the first things needed in determining cost and return of an irrigation investment is an estimate of the initial cost. This information is needed to: (1) help decide whether to pay cash for the system or finance it, and, (2) determine the annual ownership cost, which is a part of the total cost of owning, operating, and maintaining a system.

Just because an irrigation system would be profitable for a particular farm does not mean that the buyer can afford to finance it. An irrigation system may last 15 to 20 years, but many lending agencies require that they be paid for in 6 to 10 years. If this is the situation, the landowner may find himself with an annual payment that is more than the value of the expected increase in yield per year as a result of installing the irrigation system. For example, if $25,000 is borrowed to buy a system, at 15% interest for 10 years, then the annual loan payment would be $4,981 ($25,000 x 0.19925). If the expected value of the increased yield is $3,500, then the loan payments must be supplemented with additional money other than that expected from irrigating.

DETERMINING THE ANNUAL OWNERSHIP COST

The annual ownership cost is determined from the: (1) initial cost minus trade-in value of the system, (2) interest, (3) taxes and insurance, (4) fixed charges, (5) loss of income from land taken out of production for water development and (6) life expectancy of the system. Exhibit 9-2 should be completed as shown below to obtain the annual ownership cost for the system.

1. Enter in Column 2 the initial cost of the items applicable to the system and their trade-in value in Column 3. Enter in Column 4 the initial cost minus the trade-in value (Column 2 - Column 3).

2. Find the appropriate amortization factors from Table 9-1 for applicable items and enter in Column 6.

3. Compute the annual ownership cost for each item by multiplying the initial cost minus trade-in value by the appropriate amortization factor (Column 4 x Column 6) and entering in Column 7.

4. Estimate annual cost of taxes and insurance and enter it in space provided. This is estimated to be 1% of the initial cost.

5. Find the stand-by charges for electricity and enter in space provided. No electricity is being used in this example. If electricity is being used, stand-by charges can be obtained from the power supplier.

Initial and Annual Ownership Cost

Item (1)	Initial Cost (2)	Trade-in Value (3)	Initial Cost Minus Trade-in Value (4)	Expected Years of Life (5)	Amortization Factor 1/ (6)	Ow
WELL CASING						
Plastic	12,000	0	12,000	25+	.15470	1,
RESERVOIR						
PUMPS						
Line Shaft Propeller				10		
Turbine	8,500	0	8,500	15	.17102	1,
Centrifugal				12		
POWER UNIT						
Electric				25		
Gasoline				10		
Diesel	8,000	2,000	6,000	12	.18448	1,
Natural Gas, LPG, OR Propane				10		
LAND DRAINAGE				20		
LAND LEVELING				15		
WATER PIPE						
Underground Pipe						
Plastic	9,000	0	9,000	25+	.15470	1,
Aboveground Pipe						
Aluminum				15		
Galv. Steel						
PIPE TRAILER				10		
SPRINKLER SYSTEMS						
Hand-Moved				15		
Center-Pivot	60,000	15,000	45,000	10	.19925	8,
Big Gun				12		
Permanent (Solid-Set)				20		
SUBIRR. SYSTEMS						
Ditches				25		
Pipelines				20		
Structures						
MISCELLANEOUS						

Total Initial Cost 97,500

Taxes and Insurance (Total Cost x .01) = $97,500 x 0.01 = 975.00

Stand-By (Fixed Charges) for Electricity = -

Loss of Income Due to Acreage out of Production ($ - /Acre x - Acres) =

Total Annual Ownership Cost(Column 7) = $15,750.50

1/ 15% Interest Rate Used (Factors from Table 9-1)

Exhibit 9-2. Initial and Annual Ownership Cost

6. Determine a value for the loss of production from the land taken out of production. For this example, no loss is involved since a well supplies the water and uses a negligible amount of land. If a pond, lake, or reservoir is the water source, the value of any loss of production from the former use of the land should be considered.

7. Find the total annual ownership cost by adding the figures in Column 7 and enter in space provided.

Table 9-1. Amortization 1/ Factors

Expected No. of Years of Life	10%	11%	12%	13%	14%	15%	16%	17%
2	.57619	.58393	.59170	.59948	.60729	.61512	.62296	.63083
4	.31547	.32233	.32923	.33619	.34320	.35027	.35738	.36453
6	.22961	.23638	.24323	.25015	.25716	.26424	.27139	.27861
8	.18744	.19432	.20130	.20839	.21557	.22285	.23022	.23769
10	.16275	.16980	.17698	.18429	.19171	.19925	.20690	.21466
12	.14676	.15403	.16144	.16899	.17667	.18448	.19241	.20047
15	.13147	.13907	.14682	.15474	.16281	.17102	.17936	.18782
20	.11746	.12558	.13388	.14235	.15099	.15976	.16867	.17769
25	.11017	.11874	.12750	.13643	.14550	.15470	.16401	.17342

1/ Amortization - Used to convert installation costs into equal annual payments.

DETERMINING THE ANNUAL OPERATION AND MAINTENANCE COST

The annual operation and maintenance cost is determined from the annual expense of operating the system. This includes (1) fuel, (2) oil, (3) repair and maintenance of equipment, (4) reservoir and field maintenance (5) additional seed, fertilizer, pesticides, and harvesting cost for the increase in yield, and (6) labor.

Annual Operation and Maintenance Costs shown in Exhibit 9-3 may be completed as shown below to obtain the annual operation and maintenance cos

1. Find the total annual cost of fuel. Table 9-2 gives the brake horsepower hours per unit of fuel. Record the values needed fr Exhibit 9-1 and Table 9-2 and follow the mathematical instructions given for Item 1. Using $1.20 per gallon for diesel fuel, the total fuel cost is $4,000.00.

Annual Operation and Maintenance Cost

	Item	Horse power Required		Number of Hours Operated		Cost Per Unit of Fuel		bhp Hours Per Unit of Fuel	Total
1.	Fuel	100	X	486	X	$ 1.20	-	14.58	$4,000.00
2.	Oil-Engine	100	X	486	X	$ 4.00	-	900	$ 216.00
3.	Oil-Gear Drive	-	X	-	X	$ -	-	-	$ -
	or Electric Motor	-	X		X	$ -		-	$
4.	Repair and Maintenance (power unit)	100	X	486	X	$0.002	per bhp		$ 97.20
5.	Repair and Maintenance	$97,500	initial cost		X	.005			$ 487.50
6.	Reservoir and Field Maintenance	$ -	initial cost		X	.005			$ -
7.1/	Additional Seed, Fertilizer, Chemicals, and Harvesting Cost (estimate)	$ 21.35	anticipated additional expense per acre X 126 (number acres)						$2,690.10
8.	Labor	0.05	hours per acre per irrigation X 9 No. of irrigations X 126 acres X $4.00 per hour						$ 226.80
9.	Total Annual Operation and Maintenance Cost								$7,717.60

1/ This value is the amount you expect to spend in addition to that which you would spend if you did not irrigate. It varies with the crop. For some crops, you may not have any additional expense.

Exhibit 9-3 Annual Operation and Maintenance Cost

Table 9-2 Annual Fuel Consumption

Fuel or Power	bhp-Hours per Unit of Fuel
Electric	1.18 per Kilowatthour
Gasoline	11.30 per gallon
Diesel	14.58 per gallon
Propane	9.20 per gallon
Natural Gas	88.93 per 1000 cubic feet

2. Find the total annual cost of oil. Table 9-3 gives the brake horsepower hours per gallon of oil. Record the values needed from Exhibit 9-1 and Table 9-3 and follow the mathematical instructions given for Item 2. Using $4.00 per gallon for oil, the total cost of oil is $216.00.

3. Find the total cost of gear oil. No cost was figured for gear oil in this example.

   If this cost is to be added, record the values needed from Exhibit 9-1 and Table 9-3 and follow the mathematical instructions given for Item 3.

4. Find the total annual cost of maintenance of the power unit. Table 9-4 gives the estimated cost of power unit repair and maintenance per brake horsepower per hour. Record the values needed from Exhibit 9-1 and Table 9-4 and follow the mathematical instructions given for Item 4. Total for this example is $97.20.

5. Find the total annual cost of repair and maintenance of the irrigation equipment. The cost used for repair maintenance of the irrigation equipment was estimated at 0.5% of the initial cost. The initial cost of the equipment is obtained from Exhibit 9-2. The total for this example is 0.005 x $97,500 = $487.50.

6. Find the total annual cost of reservoir and field maintenance. For this example, no cost was figured for reservoir and field maintenance.

   If reservoir or field maintenance is required for your irrigation system, obtain the initial cost of the equipment from Exhibit 9-2 and follow the mathematical instructions given for Item 6.

7. Estimate the total annual cost for the additional yield from irrigation by following the mathematical instructions for Item 7. If the farmer is expected to spend more for seed, fertilizer, pesticides, labor, handling or storage than he would without irrigating, estimate the cost. This will depend on his crop and the manner in which he has been farming. A figure of $21.35 per acre was used for this example.

8. Find the total annual cost of labor. Record the values needed from Exhibit 9-1 and follow the mathematical instructions given for item 8. In this example using $4.00 per hour for labor, the total cost is $226.80.

9. Find the total annual operation and maintenance cost. This is obtained by adding all items in the "Total" column. The total for this example is $7,717.60.

Table 9-3. Annual Oil Consumption (1982)

Type of Engine and Drive	bhp - Hours Per Gallon of Oil
Electric	9000
Gasoline	900
Diesel	900
Propane	1000
Natural Gas	1000
Right Angle Gear Drive	5000

Table 9-4. Annual Cost of Repair and Maintenance (1982)

Type of Power Unit	Cost Per bhp Per Hour
Electric motor and controls	$ 0
Gasoline	$ .0017
Diesel	$ .0020
Propane	$ .0013
Natural Gas	$ .0013

DETERMINING THE RETURN ON INVESTMENT

The primary purpose for estimating the total annual cost of an irrigation system is to have a figure with which to compare the value of the expected increase in production from using that system. To obtain the return on investment, Exhibit 9-4 "Return on Investment" should be completed as shown below.

1. Determine the value of the expected increase from irrigation per acre. Record the expected yield increase and value from Exhibit 9-1 and follow the mathematical instructions on Exhibit 9-4. In this example the total value of the increase in yield is $225.00 per acre.

2. Find the total annual cost per acre for irrigating. Add the total annual ownership cost from Exhibit 9-2 to the total annual operation and maintenance cost from Exhibit 9-3 and divide by the number of acres. The total in this example is $186.25 per acre.

3. Find the expected return on investment per acre from irrigating with this system. This is obtained by subtracting the total annual cost of irrigating from the value of the expected increase. The total expected return on investment per acre for this example is $38.75.

Return on Investment

1. Value per acre of expected increase from irrigation:

   75 bu yield/acre (Exhibit 9-1) x $3.00/bu (Exhibit 9-1) = $225.00

2. Total annual cost per acre of irrigation:

   $15,750.50 (annual depreciation cost - Exhibit 9-2)

   + $ 7,717.60 (annual operating cost - Exhibit 9-3)

Total = $23,468.10 - 126 number of acres (Exhibit 9-1) = $186.25

3. Expected Return per acre on Investment = $225.00 - $186.25 = $38.75

Exhibit 9-4. Return on Investment

Using the assumptions and data contained in the above example, the following analysis can be made as to the price and yield required to "break-even" (The point where the additional income due to irrigation equals the cost of irrigation):

Break-even Price for 75 bu increase = $2.48/bu
($186.25 Increase in Cost - 75 bu)

Break-even Yield for $3.00/bu corn = 62 bu/ac
($186.25 Increase in Cost - $3.00/bu)

Break-even Yield for 2.00/bu corn = 93 bu/ac
($186.25 Increase in Cost - 2.00)

NOTE: Source of format used for this section: Planning for an Irrigation System. This publication was developed by the American Association for Vocational Instructional Materials in cooperation with the Soil Conservation Service. Data in this section has been updated to approximately the 1982 to 1985 period.

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 10. IRRIGATION METHOD DESIGN

Contents

Tables

Exhibits

CHAPTER 10-A. PERMANENT/SOLID-SET SPRINKLER IRRIGATION SYSTEM

GENERAL

The example problem in this chapter is intended to illustrate the procedure to follow in the design of permanent and solid-set irrigation systems. It is understood that one example cannot illustrate all design situations or alternatives to consider when designing a permanent or a solid-set irrigation system.

DESIGN CRITERIA

Design criteria for permanent and solid-set irrigation systems is contained in the Technical Guide, Irrigation System, Sprinkler, Code 442, for South Carolina. All sprinkler irrigation systems must be designed in accordance with the criteria contained in Code 442.

EXAMPLE PROBLEM

The following example problem is intended to cover the basic design steps to follow in the design of permanent/solid-set sprinkler irrigation systems. A standard form (Exhibit 10-A-1) is used which is a useful tool in designing and recording data.

Given

1. Location: Aiken, South Carolina.

2. Field Shape: 1320 feet east to west by 660 feet north to south (20 acres).

3. Soil: Dothan loamy sand on 0 to 5 percent slopes.

4. Crop: Small vegetables - Recommended design use rate of 0.18 in./day.

5. Row direction and spacing: Rows run north to south 30 inches apart

6. Plant spacing along row: Varies.

7. Well information: 12-inch well without electric, 3 phase. Static water level At a 400 GPM pumping rate, water level centerline is at 140 feet.

8. Owner would like to operate system abou shut off valves.

9. All pipe to be buried a minumum of 30 i

Solution:

The item numbers mentioned in the step by step solution refer to the items on the "Irrigation Data Sheet" in Exhibit 10-A-1.

Step 1. Complete Items 1-4. These items provide an inventory of pertinent data at the site.

Step 2. Complete Item 5. Make a drawing to scale of the field locating buildings, trees, well and other features.

Step 3. Complete Item 6, except for acreage to be grown which will be discussed later. Guidance in selecting the moisture extraction root depths (soils moisture control zone) and the design peak use rate are to be taken from this guide, Tables 3-1 and 4-1 respectively. The weighted AWC is computed using data from item 1.

Step 4. Complete the following parts of Item 7.

a. Available water capacity (AWC) within the water control (root) zone is the product of the root zone moisture extraction depth (12 in.) times the weighted moisture holding capacity of the soil (0.08 in./in.). AWC = (12 in.)(0.08 in./in.) = 0.96 in.

b. The percent depletion recommended prior to irrigation is 40% for truck crops as set forth in the Chapter 11 of this guide.

c. The maximum net water allowed per irrigation (in.) is the product of the percent depletion allowed prior to irrigation times the water available within the root zone. The maximum net water allowed per irrigation in this example is = (0.40) (0.96 in.) = 0.38" in.

d. The net water to be applied must be less than or equal to the maximum allowed. Use the maximum for this example - 0.38".

e. Maximum application rate from table 2-6 for loamy sand, 0.38" water applied, and 4 percent predominate maximum slope = (No limit).

f. The system efficiency is assumed to be 70 percent.

g. The gross water applied per irrigation (in.) is found by dividing the net water applied per irrigation by the system efficiency. Gross water applied = 0.38 in. ÷ 0.70 = 0.54 in.

h. The peak irrigation interval (days) is determined by dividing the net water applied per irrigation by the crop peak consumptive use rate. Peak irrigation interval = 0.38 in. ÷ 0.18 in./day = 2.1 days.

i. Normally, the irrigation period in days to be used in the formula for determining Q_R is the irrigation interval (2.1 days) determined above. However, in this example the field was broken up into four irrigation units of 5 acres each which resulted in two units being irrigated each day (10ac/day). Therefore, one (1) day was entered in each column for the irrigation period and 5 acres per irrigation unit in Item 6. The advantages of dividing the field into four units is that a smaller pump can be used and a small well capacity is required.

h. Four hours operating per day per plot was requested by the owner; however, do not enter this value yet.

Step 5. Tentatively determine the quantity of water required Q_R for each irrigation unit. Use the formula:

$$Q_R = \frac{453\ Ad}{F\ H}$$

Where Q_R = minimum required discharge capacity in gallons per minute

A = acreage of the design area

d = gross depth of application in inches

F = number of days allowed for completion of one irrigation

H = number of actual operating hours per day

$$Q_R = \frac{453 \times 5 \text{ acres} \times 0.54 \text{ in. gross application}}{4 \text{ hrs operating per day} \times 1 \text{ day per irrigation}}$$

Q_R = 306 gpm

Note that the Q_R should not exceed the well capacity. In situations where the well capacity is exceeded then the irrigation unit acreage would need to be decreased or the operating hours per day increased or a well of higher capacity would have to be installed.

Step 6. Select a sprinkler spacing that is compatible with farming operations. Some alternatives would be 40 ft by 60 ft or 60 ft by 60 ft. The 40 ft by 60 ft in a rectangular pattern was tentatively selected.

Step 7. Check the sprinkler spacing requirement in the Technical Guide Code 442. Irrigation will be done under average wind conditions (less than 5 mi/hr). The sprinkler spacing should be no greater than 50% of the wetted diameter and the lateral spacing should be no greater than 65% of the wetted diameter.

Step 8. Select a sprinkler. There are two requirements for which the sprinkler selection is to be based: (1) the wetted diameter must be at least 92.3 feet. This is computed by dividing the lateral spacing of 60 feet by the required maximum spacing of 65% of the wetted diameter (60 ft ÷ 0.65 = 92.3 ft); (2) the minimum required gpm of the sprinkler. The following formula is used to determine the gpm/spk:

$$\text{App. rate (in./hr)} = \frac{\text{gpm/spk} \times 96.3}{S \times L}$$

Where S = Spacing of sprinklers along lateral

L = Spacing between laterals in feet

For a tentative application rate, divide the gross application of 0.54 inches by the hours operating per day (4 hrs) which results in 0.135 inches per hour. Now solve the formula for gpm/spk:

$$\text{gpm/spk} = \frac{0.135 \text{ in./hr} \times 40 \text{ ft} \times 60 \text{ ft}}{96.3}$$

gpm/spk = 3.36 gpm

With the two sprinkler requirements of 3.36 gpm and 92.3 feet wetted diameter, refer to the sprinkler manufacturer's charts. Table 10-A-1 shows a typical manufacturer's sprinkler data and was used to select the sprinkler. The sprinkler selected has a capability of 3.84 gpm @ 45 psi with a wetted diameter of 92 feet which meets the criteria. The nozzle size is 9/64 inches. This data was entered in Item 9.

Step 9. Complete Item 8.

a. Application rate is recomputed using the formula:

$$\text{Application rate (in./hr)} = \frac{\text{gpm/spk} \times 96.3}{S \times L} = \frac{3.84 \times 96.3}{40 \times 60} = 0.15$$

b. Time per lateral or unit set in hours is computed by dividing the gross application of 0.54 in. by the application rate of 0.15 in./hr. Time per lateral set = 0.54 in. ÷ 0.15 in./hr = 3.6 hr.

c. Determine the number of sprinklers per unit. Divide the field using the drawing prepared in Step 2 into 4 as nearly

equal units as possible. Place the sprinklers, pipe layout and valves on the plan. Label each unit and place it on the drawing. Count the number of sprinklers per unit and enter in Item 8. Units have 88 sprinklers.

d. Determine the actual gpm/unit, Q_A per unit. Multiply the number of sprinklers per unit times the gpm/spk to determine gpm/unit.

Units: 88 spk x 3.84 gpm/spk = 338 gpm

Step 10. Complete the last entry of Item 7. Enter the actual hours operating per day of 3.6 hours as calculated in Step 9.b. The Q is obtained by the following formula:

$$Q_R = \frac{453 \times 5 \text{ acres} \times 0.54 \text{ in. gross application}}{3.6 \text{ hrs operating per day} \times 1 \text{ day per irrigation}} = 340 \text{ gpm}$$

Note that as a check, the Q_A should be approximately equal to Q_R.

Step 11. Determine Total Dynamic Head. Refer to Item 10, as each of the following points are discussed:

a. Size the lateral and submain to determine its head loss. Usually the longest lateral and submain is used to determine the head loss within the irrigation unit. However, ground elevation changes may sometimes cause the maximum head loss to occur elsewhere. This will be discussed a little later in this step. Sheets 4 and 5 of Exhibit 10-A-1 Pipe Sizing Data Sheet were used for this purpose. First, the gpm for the lateral and submain was listed in a cumulative manner beginning with the last sprinkler. The length of pipe carrying the corresponding gpm was then listed. Then using Appendix C, the pipe was sized and corresponding friction head loss (HL_f) in ft/100 ft listed on the data sheet. The pipe is sized so that the velocity of water flow through the pipe is less than or equal to 5 fps. The total friction head loss is determined by multiplying the HL_f (ft/100 ft) x the pipe length (ft) and suming the results. The elevation differences are then totaled and added to the total friction head loss to obtain the total head loss in the lateral. The summation of 6.38 ft was used in the design.

Elevation difference of natural ground between the risers and within an irrigation unit must be evaluated for each design as it can affect the layout of the irrigation unit and the pipe sizing. It affects the layout because the nozzle pressure must be maintained within certain limits in each irrigation unit. These limits are discussed in Step 13.

The effect that elevation difference has on pipe sizing can best be explained using an example. For instance, if

a lateral is to be installed downhill from the mainline, a smaller pipe with higher friction head loss may be used. The elevation difference is downhill (increase in pressure) which offsets the decrease in pressure due to friction head loss. An increasing elevation plays a reverse role often resulting in a larger diameter pipe.

b. The head loss for the irrigation unit is then modified so that the theoretical mid-system sprinkler is operating at the design nozzle pressure. This provides for a more balanced system in that the sprinkler closer to the pump operates at a pressure a little higher than the design nozzle pressure and the farthest sprinkler a little lower in pressure. The head loss can be modified by multiplying the summation of 6.38 ft x 0.5 = 3.19 ft. (The factor 0.75 would be used if this was a single pipe size lateral because approximately 75 percent of the pressure loss in a single pipe size lateral with uniformly decreasing discharge has already occurred at the midpoint of the lateral.) Assume the sprinklers within an irrigation unit are desired to operate at a pressure within ± 10% of the design operating pressure. Technical Guide Code 442 allows maximum variation of ± 20 percent. In this case, with the design operating pressure at 45 psi, the allowable variation in sprinkler operating pressure is ± .10 x 45 psi = ± 4.5 psi. Therefore, 45 psi ± 4.5 psi = 40.5 psi and 49.5 psi for the minimum and maximum sprinkler operating pressure.

c. Size the mainline and determine the head loss. Item 10 could have been used for sizing and determining the mainline head loss since no elevation changes were involved but the pipe sizing data sheet was used for the mainline also. The 6 in. main with 338 gpm has a friction head loss of 0.69 ft/100 ft. Total head loss is equal to 0.69 ft/100 ft x 495 ft = 3.43 ft. The 3.43 ft is equal to 1.48 psi.

d. Determine the recommended maximum working pressure. This is the class of pipe (160 psi) multiplied by 0.72 = 115 psi since it is assumed special surge and water hammer control is not to be provided. Do not compute actual working pressure until later in the design.

e. Design sprinkler nozzle pressure. The 45 psi sprinkler operating pressure was determined in Item 9. Remember that this is the operating pressure of the theoretical mid-sprinkler of the irrigation unit.

f. Miscellaneous and fitting friction losses. This can be computed using the formula $h = (Kv^2/2g)$ where values of K are in Appendix C. However, this is usually estimated to be within a range of 1.3 psi to 3.5 psi depending on the complexity of the system. This example was estimated to have about 1.3 psi head loss for miscellaneous and fitting losses.

g. Riser height. The height required to get the sprinkler above the vegetation to prevent distortion of the water. In this case, 3 feet is required.

h. Pump discharge pressure (at the entrance to the main pipe line). This is the pressure the pump must produce so that the theoretical mid-sprinkler of the irrigation unit is operating at its design operating pressure of 45 psi. To obtain the pump discharge pressure the preceding items were totaled as follows:

Lateral & sub-main friction losses	-	1.38 psi
Mainline friction losses	-	1.48 psi
Nozzle pressure	-	45.00 psi
Miscellaneous & fittings friction losses	-	1.30 psi
Riser height	-	1.30 psi
Pump discharge pressure		50.5 psi

i. Maximum pipe working pressure in main. This is the same as the pump discharge pressure just determined (50.5 psi). From step 11-d, maximum recommended working pressure for the 6" class 160 pipe is 115 psi, thus the pipe strength is adequate throughout.

j. Pumping lift. This is discussed in Chapter 6. It is the vertical distance the pump must lift the water in the well to reach the ground level (main inlet) or in the case of a centrifugal pump the vertical distance plus losses (suction lift) from the water elevation at maximum drawdown to the pump discharge. The pump-drawdown is considered in determining the pumping lift. This example has the static water level at 75 feet with 50 feet of drawdown when pumping. Therefore the pumping lift is 75 ft + 50 ft = 125 ft which is equal to 54.1 psi.

k. Total dynamic head (TDH). This is the total head loss that the pump must operate against in order for it to perform the required work. The pump discharge pressure (50.5) psi + pumping lift (54.1 psi) = 104.6 psi TDH. This is usually expressed in feet which would be 241.6 ft TDH. (use 242 ft.)

l. Net positive suction head available (NPSHA). This represents the energy available to move the fluid(water) into the eye of the impeller.

NPSHA = 144 (Pa - Pv)/w - h_f + z
where the minimum probable value for the term 144 (Pa - Pv)/w @ 70°F @ sea level ≅ 144 (13.57 - 0.37)/ 62.3 = 30.49, use 31 ft. This value (31 ft) may be used throughout the piedmont (up to 1000 ft about sea level) and lower lying areas of S.C. for acceptable accuracy. For higher lying areas (up to about 4000 ft above sea level) the value should be reduced about one ft for each 1000 ft rise in elevation.

h_f = head loss (ft) due to friction in inlet line and at the impeller entrance (use 3 ft as average value in most situtations).

z = elevation difference between pump centerline and the water surface (assume 20' for this example). If the suction water surface is below the pump centerline, z is negative. Therefore, NPSHA ≅ 31 - 3.0 + 20.0 = 48 ft.

Step 12. Complete Item 11, Pump Requirement. This is the maximum gpm the pump must produce at a given TDH and minimum net positive suction head. From Item 8, the maximum Q_A for an irrigation unit is 338 gpm. The TDH from the preceding section is 242 feet. The NPSH required must be less than 48 ft. Therefore, the pump requirement would be expressed as 338 gpm at 242 feet TDH with NPSH less than 48 ft.

Step 13. Complete Item 12, Power Unit Requirement. This is the brake horsepower needed at the output from the power unit to supply power to the pump. The pump efficiency would be obtained from the characteristics curve for the particular pump to be used. A value of 0.70 would be a reasonable value for some pumps, use 0.7. The drive efficiency for a direct connected electric motor is approx. 100 percent, use 1.00. Therefore, compute BHP using gpm and TDH from the preceeding step.

$$\text{BHP} \geq \frac{338 \text{ gpm} \times 242 \text{ ft TDH}}{3960 \times 0.7 \times 1.0} = 29.5$$

Step 14. Complete Item 13. Check the sprinkler pressure variation within the system (Irrigation Units) against the allowable. This was discussed earlier under Item 11.b. The actual is found by using sheet 4 of 5 of Exhibit 10-A-1. The actual nozzle pressure of the closer sprinkler is the pump discharge pressure (50.5 psi) - the mainline losses (1.48 psi) - miscellaneous and fitting friction losses (1.30 psi) - the riser height loss (1.30 psi) = 46.4 psi. The actual nozzle pressure of the farthest nozzle is the pump discharge pressure (50.5 psi) - the mainline loss (1.48 psi) - miscellaneous and fitting friction losses

(1.30 psi) - the riser height loss (1.30 psi) - actual total lateral and sub-main losses (2.8 psi) = 43.6 psi.

The allowable nozzle pressure as taken from section 11.b. is 40.5 psi (minimum) and 49.5 psi (maximum). The actual nozzle pressure of 43.6 psi and 46.4 psi is within this range.

Table 10-A-1. Typical Sprinkler Manufacturer's Data

Highest point of stream is 7' above nozzle.*

psi@ Nozzle	Nozzle 7/64" diam	gpm	Nozzle 1/8" diam	gpm	+Nozzle 9/64" diam	gpm	Nozzle 5/32" diam	gpm	Nozzle 11/64" diam	gpm
25	78	1.73	82	2.25	85	2.90	88	3.52	90	4.24
30	79	1.89	84	2.47	87	3.16	90	3.85	92	4.64
35	80	2.05	85	2.68	89	3.40	92	4.16	94	5.02
40	81	2.20	86	2.87	91	3.63	94	4.45	96	5.37
45	82	2.32	87	3.05	92	3.84	96	4.72	98	5.70
50	83	2.44	88	3.22	93	4.04	98	4.98	100	6.01
55	84	2.56	89	3.39	94	4.22	100	5.22	102	6.30
60	85	2.69	90	3.55	95	4.28	101	5.54	103	6.56

+Standard Nozzle.
*Shown for standard nozzle at normal operating pressure. Area below dotted line in chart is the recommended working pressure for best distribution.

LAYOUT CONSIDERATIONS

Items that must be considered in the layout of a permanent and solid-set irrigation system area as follows:

a. Soil limitations which may affect the ease of installation such as cut banks caving, depth to rocks and wetness.

b. Plant spacing and row direction so that riser can be properly located.

c. Maximum height of plants for determing riser height.

d. Location of obstacles such as ponds, fences, overhead power lines and buried electrical and gas lines which are safety hazards.

e. Topography which may affect the layout of the system and valving arrangement so that each irrigation unit can be operated within the allowable pressure variation.

CONSTRUCTION REQUIREMENTS

Construction items that must be checked to be assured of a quality installation are as follows:

a. The depth of cover over the buried main line must be adequate for protection from vehicular traffic and the farming operation.

b. Thrust block dimensions, location and alignment to prevent pipe joint separation.

c. Location and size of air vents and pressure relief valve. Risers function as air vents but others may be required if a pipeline has a summit with no riser.

d. Riser material, diameter, height and spacing.

e. Sprinkler model and size nozzle. Location of part circle sprinklers if planned.

f. Location and size of valves which serve each irrigation unit.

g. Depth of cover over the buried pipe.

h. Verify the pipe requirements such as SDR number, pressure rating, ASTM designation, PVC material, pipe diameter and if PIP or IPS pipe.

i. Check valve installed at pump discharge.

j. Verify pump, motor and well size. Then check the nozzle pressure and variation within each irrigation unit using a pressure gauge with a pitot tube.

IRRIGATION DATA SHEET

System type (circle): Center Pivot, Traveling Gun, Permanent, Solid Set (Other, list)

CONSERVATION DISTRICT Aiken FIELD OFFICE Aiken
COOPERATOR John Doe LOCATION " Co.
IDENTIFICATION NO. System No. 1 FIELD NO. 2

1. Design area 20 acres (Area actually irrigated)
   Soil series Dothan

   Design Soil Series: Dothan Predominate maximum slope 4 %

Soil Depth (in.)	Texture (USDA)	Average AWC (in./in.)
0-11	L.S.	.08
11-31	S.L.	.14
use 0-12	LS	.08

2. Crops:

Crop	Acres	Planting Date	Maturity Date
S. Veg.	20	Varies	Varies
Total	20		

3. Water supply:
   Source of supply: (stream, well, reservoir, etc.) 12"

   Stream: Measured flow (season of peak use) — gpm

   Reservoir: Storage — ac. ft. Available for irrigation — ac. ft.

   Stream or Reservoir: Maximum drawdown available — ft.; Maximum elevation lift on intake side of pump — ft.

   Well: Static Water Level 75
   Measured Capacity 400 gpm @ 50 ft drawdown
   Design Pumping Lift 125 ft (to ground level - main pipeline inlet)
   Pump Impeller Level 140

   Distance supply source (main pipeline inlet) to field 0 ft

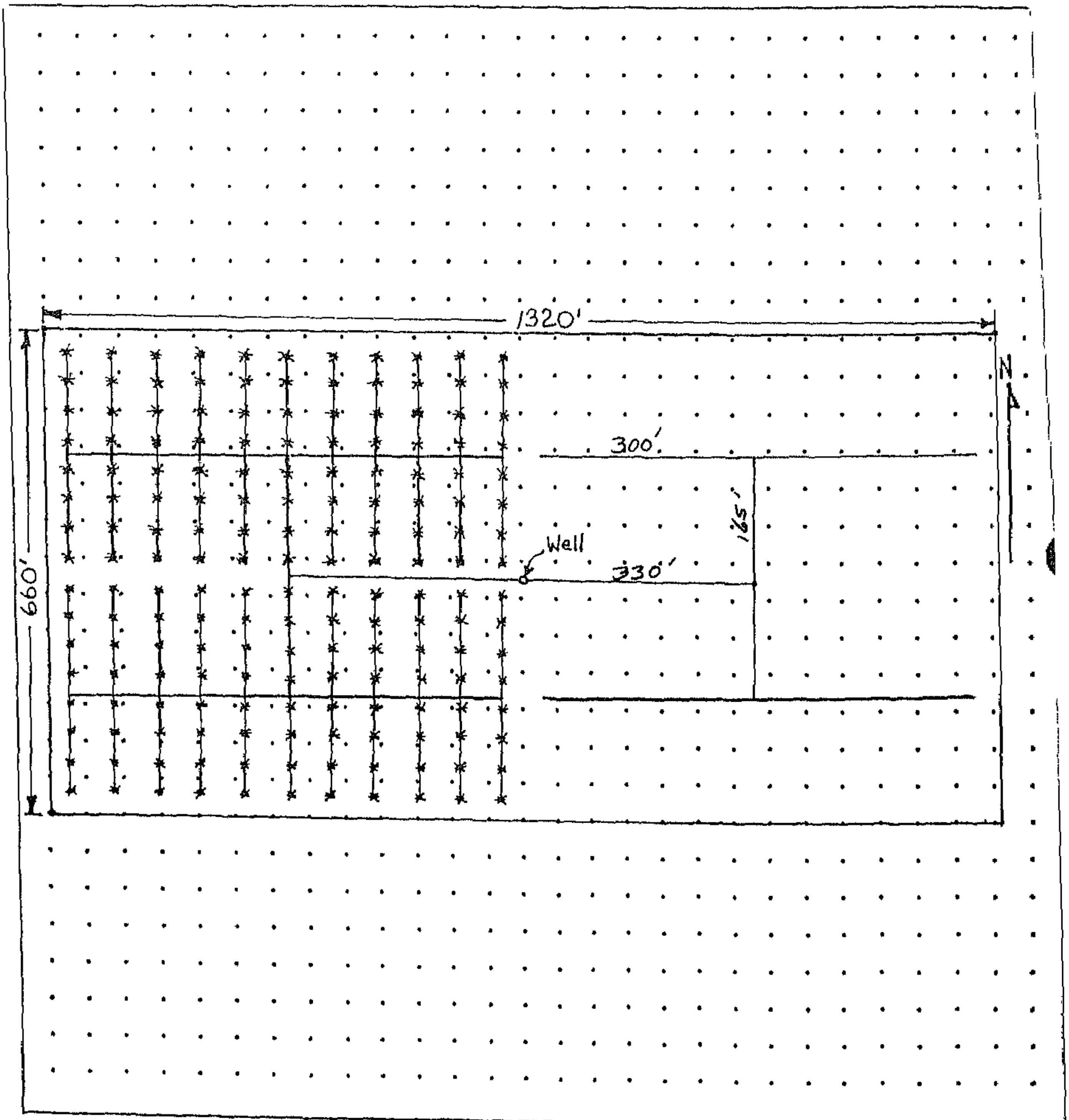
   Quality of water (evidence of suitability): No apparent problems

4. Other Data:
   Type of power unit and pump to be used: Electric - 3 Ph.

PERM./SOLID-SET SPRINKLER IRRIG. SYSTEM

Cooperator: John Doe Designed by: Tom Jones Checked by: A. Engineer

5. Map of design area - Scale 1" = 200 ft
   Sketch map on grid or attach photo or overlay.



Sketch map should show:

a. Source of water
b. Major elevation differences
c. Row direction
d. Sprinkler system layout
e. Plan of operation
f. Field obstructions (gullies, trees, buildings, etc.)
g. North arrow

PERM./SOLID-SET SPRINKLER IRRIG. SYSTEM

Cooperator: John Doe Designed by: Tom Jones Checked by: A. Eng.

6. Crop Information	IRRIGATION UNIT NUMBER 1	2	3	4
Kind of crop	Small Veg.			
Acreage to be irrigated (acres) 1/	5			
Depth of soil water control zone (in.)	12			
Peak use rate (in./day)	0.18			
Weighted AWC for water control zone(in./in)	0.08			

7. Design Procedure	1	2	3	4
AWC within water control zone (in.)	0.96			
Depletion allowed prior to irrigation (%)	40			
Maximum net water allowed per irrig. (in.)	0.38			
Net water applied per irrigation (in.)	0.38			
Max. recommended application rate (in./hr.)	No limit			
System efficiency (%)	70			
Gross application per irrigation (in.) 1/	0.54			
Peak irrigation interval (days)	2.1			
Irrigation Period (days per irrig.)	1			
Hours operating per day	4			
Q_R = Quantity of water required (gpm) 1/	340			

8. Irrigation Unit Design	1	2	3	4
Application Rate (in./hr) 2/	0.15			
Actual Time per lateral or unit set (hrs = gross application / application rate)	3.6			
Number of sprinklers per unit	88			
Q_A 3/ = Quantity of water actual (gpm/unit) = No. of sprinklers/unit x gpm/spk.)	338			

9. Sprinkler Specifications:

a. sprinkler spacing 40 ft, lateral spacing 60 ft

b. nozzle size 9/64" x — wetted diameter 92 ft

c. capacity 3.84 gpm @ 45 psi or 104 ft

1/ $Q_R = \dfrac{453 \times 5 \text{ acres} \times 0.54 \text{ in. gross application}}{4.0 \text{ hrs opr. per day} \times 1 \text{ days per irrigation}}$ = 306 gpm

2/ Application rate (in./hr) = $\dfrac{\text{gpm/spk} \times 96.3}{S \times L}$ MUST BE $\leq$ MAXIMUM RECOMMENDED RA

Where S = Spacing of sprinklers along lateral in feet.

L = Spacing between laterals in feet.

3/ Q_A = maximum unit gpm: Must be approximately equal to Q_R

PERM./SOLID-SET SPRINKLER IRRIG. SYSTEM

Cooperator: John Doe Designed by: Tom Jones Checked by: A. Eng.

10. Determining Total Dynamic Head 4/

Kind of Pipe: Main	Kind of Pipe: Sub-Main	Kind of Pipe: Lateral	Design Capacity (gpm)	IPS PIP Other___ Diameter (in.)	Length (ft)	Friction Head Loss 5/ (ft/100ft)	Total Head Loss HL (ft)	Total Head Loss, HL (ft)	Total Head Loss, HL (psi)	Working Pressure: Recommended Max 6/ (psi)	Working Pressure: Act Max (ps
XXXX	✓	✓	(see attached pipe calculations)				6.38	XXXX	XXXX		
XXXX								XXXX	XXXX		
XXXX								XXXX	XXXX		
XXXX								XXXX	XXXX		
XXXX								XXXX	XXXX		
XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	6.38	3.19 7/	1.38		
✓	XXXX	XXXX					XXXX	3.43	1.48	115.	5
	XXXX	XXXX					XXXX				
	XXXX	XXXX					XXXX				
	XXXX	XXXX					XXXX				
	XXXX	XXXX					XXXX				
Design Sprinkler Nozzle Pressure								104.0	45.0		
Miscellaneous and Fitting Losses (usually 3 psi +)								3.0	1.3		
Riser Height								3.0	1.3		
Pump Discharge Pressure (at main pipeline inlet)								116.6	50.5		
Pumping Lift (including losses)								125.0	54.1		
Total Dynamic Head, TDH								241.6	104.6		
Estimated Net Positive Suction Head Available, NPSHA								48	—		

11. Pump Requirements: 338 gpm @ 104.6 psi or 242 ft of head and NPSH less than 48 ft.

12. Power Unit Requirement:

$$BHP \geq \frac{338 \text{ gpm} \times 242 \text{ ft TDH}}{3960 \times 0.7 \text{ pump eff.} \times 1.0 \text{ drive eff.}} = 29.5$$

13. Check pressure variation within system (irrigation unit).
    Allowable = ± 10 % of nozzle operating pressure = ± 4.5 psi.
    Allowable = 40.5 psi to 49.5 psi
    8/ Actual = 43.6 psi to 46.4 psi

4/ Use pipe sizing data sheets where elevation differences are present and/or additional data lines needed.

5/ Keep velocity ≤ 5 fps unless means to control surge and water hammer are otherwise adequate.

6/ For plastic pipe, pressure rating divided by 0.72 unless means to control surge and water hammer are otherwise adequate.

7/ Sets optimum nozzle pressure at a theoretical mid-system sprinkler.

8/ Consider elevations and location. Adjust 7/ if possible to stay within allowed variation. If not, the system must be redesigned.

Design approved by: Tom Jones Date: 2/2/86

PIPE SIZING DATA SHEET

Sheet 5 of 5

Cooperator John Doe

Field Office Aiken

Designed by Tom Jones

Checked by A. Engineer

Pipe Material PVC, SDR 26 IPS☑ PIP☐ Other

Irrigation Unit No. Main	Sub-Main	Lateral	Design Capacity (gpm)	Pipe Diam. (in.)	Length (ft)	HL_f (ft/100')	Multiple Outlet Factor	Total HL_f (ft)	Elevation Difference HL_e (ft)	Total HL $HL_f + HL_e$ (ft)	Remarks
		✓	3.84	1	40	0.49		0.20	0.20	0.40	(All pipe is PVC
		✓	7.68	1	40	1.79		0.72	0.10	0.82	type 1120 material)
		✓	11.52	1¼	40	1.16		0.47	0.10	0.57	
		✓	15.36	1¼	20	1.94		0.39	0.20	0.59	
	✓		30.72	2	60	1.21		0.73	-0.20	0.53	
	✓		61.44	2½	60	1.72		1.03	-0.10	0.93	
	✓		92.16	3	60	1.41		0.85	0	0.85	
	✓		122.88	3½	60	1.25		0.75	0.10	0.85	
	✓		153.60	4	60	1.06		0.64	0.20	0.84	
							Σ	5.78	0.60	6.38	½ Total HL = $\frac{6.38}{2}$ = 3.19 1/
✓			337.92	6	495	0.69		3.43	0	3.43	class 160 pipe

1/ Modification to provide for theoretical mid-system pressure to be at optimum pressure used for design.

CHAPTER 10-B. TRAVELING GUN SPRINKLER IRRIGATION SYSTEM

GENERAL

The example problem in this chapter is intended to illustrate the procedure to follow in the design of traveling gun irrigation systems. It is understood that one example cannot explain all design situations or alternatives to consider when designing traveling gun sprinkler irrigation systems.

DESIGN CRITERIA

Design criteria for traveling gun sprinkler irrigation system is contained in Technical Guide, Irrigation System, Sprinkler, Code 442, for South Carolina. All traveling gun sprinkler irrigation system must be designed in accordance with the criteria contained in Code 442. Guidelines for line spacings may be obtained from this chapter.

EXAMPLE PROBLEM

The following example problem is intended to cover the basic design steps to follow in the design of traveling gun sprinkler irrigation systems. A standard form (Exhibit 10-B-1) is used which is a useful tool in designing and recording data.

Given:

1. Existing Nelson 200 gun, 27° trajectory, 1 3/4" Ring Nozzle, 270° angle of operation.
2. Crop & Acres: 40 acres soybeans
   28 acres peanuts
3. Soil: Fuquay Sand
4. Location: Orangeburg, South Carolina
5. Slope: Maximum 6%
6. Pump capability (existing): 500 gpm @ 320 ft TDH; 600 gpm @ 350 ft TDH; 700 gpm @ 400 ft TDH
7. Crop Rows: North and South

Solution:

All item numbers mentioned in the step by step solution refer to the items on the standard form "Irrigation Data Sheet" in Exhibit 10-B-1.

Step 1. Complete Items 1-4. These items provide an inventory of pertinent data of the site.

Step 2. Complete Item 5. Make a drawing to scale of the field locating trees, buildings, well and other features.

Step 3. Complete Item 6. Guidance in selecting the moisture extraction root depths (soil water control zone) and the design peak use rate are to be taken from this guide, Tables 3-1 and 4-1 respectively. The weighted AWC is computed using data from item 1.

Step 4. Complete the following parts of Item 7 (the figures used in the following steps will be specifically oriented to the soybeans, the crop with the larger peak consumptive use).

a. Available water capacity (AWC) within the water control (root) zone is the product of the root zone moisture extraction depth (24 inches) times the moisture holding capacity of the soil (0.05 in./in.) AWC = (24 in.)(0.05 in./in.) = 1.20 in.

b. The percent depletion allowed prior to irrigation is selected to be 50%.

c. The maximum net water applied per irrigation (in.) is the product of the percent depletion allowed prior to irrigation (50%) times the water available within the root zone. The maximum net water applied per irrigation is = (0.50)(1.2 in.) = 0.60 in.

d. The net water to be applied should be less than or equal to the maximum allowed. Use the maximum for this example - 0.6 inches.

e. Maximum application rate from table 2-6. Use 0.8" per hour or less.

f. The water application efficiency is selected to be 70% (average for day and night irrigation).

g. The gross water applied per irrigation (in.) is the net water applied (0.60 in.) divided by the system efficiency (70%). Gross water applied = 0.60 in. ÷ 0.7 = 0.86 in.

h. The peak irrigation interval (days) is the net water applied (0.60 inches) divided by the design peak use rate (0.30 in./day). Peak irrigation interval = 0.60 in. ÷ 0.30 = 2.0 days.

The irrigation period to be used in the formula for determing the Q_R is the irrigation interval, 2.0 days.

j. The hours operating per day were discussed with the owner who advised that he irrigated continuously until completed. Therefore, the 20 hours were agreed upon providing another 4 hours for moving the equipment.

k. Now determine the quantity of water required (gpm) using the formula as follows:

$$Q_R = \frac{453\ Ad}{FH}$$ (See page 10-A-3 for explanation of formula.)

$$Q_R = \frac{453 \times 68 \text{ acres} \times 0.86 \text{ inches gross application}}{20 \text{ hrs opr. per day} \times 2.0 \text{ days per irrigation}}$$

$$Q_R = 662 \text{ gpm}$$

Step 6. Complete Item 8, Irrigation Unit Design.

a. Keeping in mind the capability of the pump (see sheet 10-B-1) and the minimum Q required of 662 gpm, determine the nozzle size, sprinkler gpm, and nozzle pressure. Using the Volume Gun Performance Tables (Table C-27) with a ring nozzle size of 1 7/8 inches, a capacity of 675 gpm at 80 psi and a wetted diameter of 470 feet was selected.

b. Determine the lane spacing using approximately 60-65% of the wetted diameter of the sprinkler assuming a wind speed of 5 to 10 mph (see Table 10-B-1, p. 10-B-7). The total length of the field is 1,660 feet. The spacing of 290 ft between risers was tentatively selected which is 62% of the wetted diameter. Now, in order to properly irrigate the ends of the field, the riser needs to be approximately 75% of the wetted radius away from the field boundary (i.e., .75 x 235 ft) or 176 feet. Now determine the distance actually available by dividing the distance 1,800 ft. by 290 ft. = 6.21 spaces. Take 1.21 spaces x 290 ft/space = 350 ft. and place half of this (175 ft) distance at each end of the field between the riser and field boundary. The 175 feet is adequate.

c. The application rate is computed using the following formula:

$$\text{Application rate (in./hr)} \cong \frac{96.3 \times \text{sprinkler gpm, } q}{(0.81)\ 3.14\ (r)^2} \times \frac{360}{w}$$

$$= \frac{13630 \times q}{r^2\ \ w}$$

where r = wetted diameter/2 = 235'
w = portion of circle receiving water, degrees, use 270.

$$\text{Application rate} = \frac{13630 \times 675}{(235)^2\ \ 270} = 0.62 \text{ in./hr.}$$

d. The travel speed is computed by the following formula:

Travel Speed (ft/min)

$$= \frac{1.605 \times \text{sprinkler gpm}}{\text{lane spacing (ft)} \times \text{gross water applied (in.)}}$$

$$= \frac{1.605 \times 675}{290 \times 0.86} = 4.34 \text{ ft/min for soybeans}$$

e. Time per 660 ft. run (hrs) $= \frac{660 \text{ ft}}{4.34 \text{ ft/min}} \times \frac{1 \text{ hr}}{60 \text{ min}}$

$= 2.53$ hours

Step 7. Complete Item 9, Sprinkler Specification.

Step 8. Make a scaled plan layout of the system. Pipe sizes etc., will be added later.

Step 9. Complete Item 10. Size the mainline and determine the Total Dynamic Head required for the pump:

a. Use a 8-inch diameter PVC, SDR 26, class 160 IPS pipe. A length of 1725 ft was determined from the layout. The friction head loss is 0.69 ft/100 ft and is taken from Appendix C. The total head loss for the 8-inch PVC is 0.69 ft/100 ft x 1725 ft = 11.9 ft. The recommended maximum working pressure in the pipe is 0.72 x 160(class rating) = 115 psi since it is assumed special means to control surge and water hammer will not be provided. Do not enter the actual working pressure yet.

b. Using 660 ft of 5 inch flexible hose, the friction loss taken from Exhibit C-1 is 2.0 psi/100 ft or 4.62 ft/100 ft. Total head loss for the hose is 660 ft x 4.62 ft/100 ft = 30.5 ft. Table 10-B-2 is a guide for flexible hose selection.

c. Enter the sprinkler pressure at the nozzle, miscellaneous losses and elevation differences between the main pipeline inlet and the nozzle when located on the high point in the field.

d. The sum of a, b, and c gives a pump discharge pressure at the main pipeline inlet required of 249.1 feet of head or 107.84 psi. Enter this value also as the actual maximum working pressure in the main.

e. The pumping lift (suction lift in this example) is the sum of the static suction lift and friction losses in suction pipe and miscellaneous inlet fittings. The static suction lift is 15 ft. from item 3. The friction loss in 6 inch inflow line (30 linear ft, 5" PVC SDR-26) is 5.9 ft/100 ft x 30 ft = 1.77 ft. The losses in the inlet fittings may be calculated using appropriate head loss coef. k from Table C-18. Usually these losses are $\leq$ 2 feet, use 2 ft. The total pumping lift is approximately 15.0 + 1.77 + 2.0 = 18.77 (use 19 ft).

f. The total dynamic head is the pumping lift plus the pump discharge pressure, 19.0 ft + 249.1 ft = 268.1 ft = 116.06 psi.

g. The minimum net positive suction head available (NPSHA) is approximately equal to 31.0 - suction lift = 31.0 - 19.0 = 12.0 ft (see example in section 10-A and Chapter 6 of this guide for more information).

Step 10. Complete item 11. The pump requirement of 675 gpm at 268 feet of head (TDH) is within the capability of the pump. Although not given for this pump, the NPSH required must be less than about 12.0 ft or cavitation is likely.

Step 11. Complete item 12, Power Unit Requirement. This is the brake horsepower needed at the output from the power unit to supply power to the pump. The pump efficiency would be obtained from the characteristics curve for the particular pump to be used. A valve of 0.70 would be a reasonable value for some pumps, use 0.7. The drive efficiency for a direct connected electric motor is approximately 100 percent, use 1.00. Therefore, compute BHP using gpm and TDH from the preceeding step.

$$BHP \geq \frac{675 \text{ gpm} \times 268 \text{ ft TDH}}{3960 \times 0.7 \times 1.0} = 65.3$$

Step 12. Complete the plans. The specifications, location of the pipe, check valve, air vents, pressure relief valve, risers, thrust blocks, etc., should be shown on the plans. See sheet 2 of 5 of Exhibit 10-B-1.

LAYOUT CONSIDERSATIONS

Items that must be considered are as follows:

a. Plant spacing and/or row direction so that travel lanes can be located properly.

b. Location of obstacles and safety hazards.

c. Whenever possible, place the risers a full hose length away from the edge of the field. This greatly facilitates laying out the hose and reeling it back up.

d. Soil limitations such as surface texture may necessitate a part circle volume gun so that the area is not irrigated in front of the gun as it moves, providing a dry footing.

e. Topography may dictate the lane direction to prevent misalignment of the traveler while in operation.

CONSTRUCTION REQUIREMENTS

The following is a list of construction items that should be checked to be assured of a quality installation:

a. The depth of cover over the buried mainline must be adequate for protection from vehicular traffic and the farming operation.

b. Thrust block dimensions and location to prevent pipe joint separation.

c. Location and size of air vents and pressure relief valve.

d. Size and proper direction of installed check valve.

e. Riser material, size, number and location.

f. Verify the pipe requirements such as SDR number, pressure rating, ASTM designation, PVC material, pipe diameter and if PIP or IPS size.

g. Verify pump, motor and well size. Check nozzle pressure.

Sprinkler Wetted Diameter	Percent of Wetted Diameter						
	50	55	60	65	70	75	80
	Wind over 10 mph		Wind up to 10 mph		Wind up to 5 mph		No Wind
ft	ft	ft	ft	ft	ft	ft	ft
200	100	110	120	130	140	150	160
250	125	137	150	162	175	187	200
300	150	165	180	195	210	225	240
350	175	192	210	227	245	262	280
400	200	220	240	260	280	300	320
450	225	248	270	292	315	338	360
500	250	275	300	325	350	375	400
550	275	302	330	358	385	412	440
600	300	330	360	390	420	---	---

Table 10-B-1. Recommended towpath spacings for traveling sprinklers with ring (lower) and tapered (higher percentages) nozzles

FLOW RANGE (gpm)	HOSE DIAMETER (Inches)
50 - 150	2.5
150 - 250	3.0
200 - 300	3.5
250 - 600	4.0
400 - 750	4.5
500 - 1000	5.0

Table 10-B-2. Guide for Flexible Irrigation Hose Selection (See Exhibit C-1, p. C-16 for friction loss table)

IRRIGATION DATA SHEET

System type (circle): Center Pivot, Traveling Gun, ____________

(Other, list)

CONSERVATION DISTRICT Orangeburg FIELD OFFICE Orangeburg
COOPERATOR John Farther LOCATION " Co.
IDENTIFICATION NO. System NO. 3 FIELD NO. 3

1. Design area 68 acres (Area actually irrigated)
   Soil series Fuquay

   Design Soil Series: Fuquay Predominate maximum slope 4

Soil Depth (in.)	Texture (USDA)	Average AWC (in./in.)
0-24	Sand	0.05

2. Crops:

Crop	Acres	Planting Date	Maturity Date
Peanuts	28	4/20	9/7
Soybeans	40	5/1	9/20
Total	68		

3. Water supply:
   Source of supply: (stream, well, reservoir, etc.) stream

   Stream: Measured flow (season of peak use) 1000+ gpm

   Reservoir: Storage — ac. ft. Available for irrigation — ac. ft.

   Stream or Reservoir: Maximum drawdown available 4 ft.; Maximum elevation lift on intake side of pump 15 ft.

   Well: Static Water Level —
   Measured Capacity — gpm @ — ft drawdown
   Design Pumping Lift — ft (to ground level - main pipeline inlet)
   Pump Impeller Level —

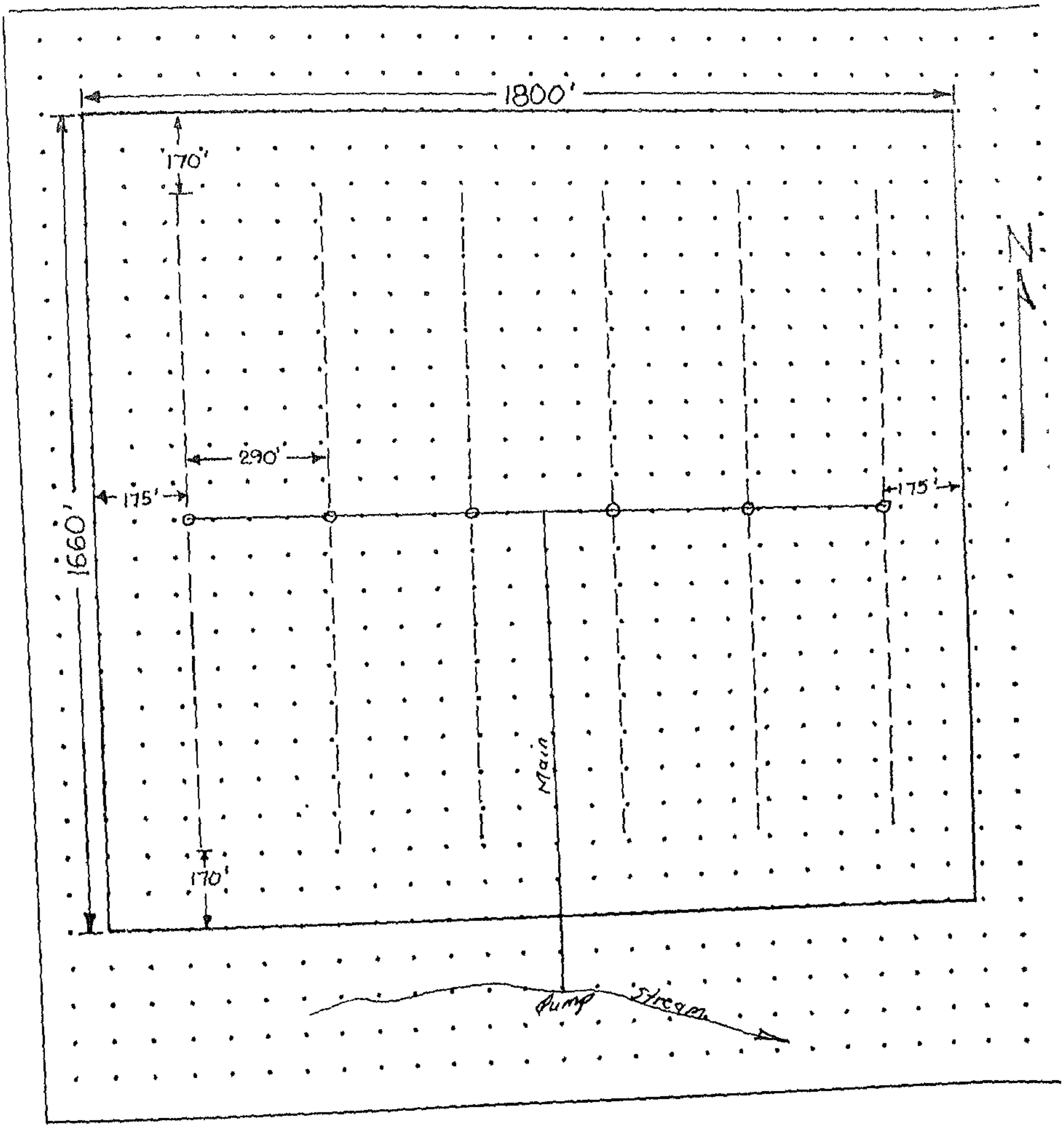
   Distance supply source (main pipeline inlet) to field 1000 ft

   Quality of water (evidence of suitability): Good

4. Other Data:
   Type of power unit and pump to be used: Diesel

Cooperator: John Farmer Designed by: Walter Jones Checked by: A Engineer

5. Map of design area - Scale 1" = 300 ft
Sketch map on grid or attach photo or overlay.



Sketch map should show:

a. Source of water
b. Major elevation differences
c. Row direction
d. Sprinkler system layout
e. Plan of operation
f. Field obstructions (gullies, trees, buildings, etc.)
g. North arrow

TRAVELING GUN IRRIGATION SYSTEM

Cooperator: J. Farmer Designed by: W. Jones Checked by: J. Stone

	IRRIGATION UNIT NUMBER			
6. Crop Information	1	2	3	4
Kind of crop	Peanuts	Soybeans	Soybeans	
Acreage to be irrigated (acres) 1/	28	40	68	
Depth of soil water control zone (in.)	18	24	24	
Peak use rate (in./day)	.25	.30	.30	
Weighted AWC for water control zone (in./in)	.05	.05	.05	
7. Design Procedure				
AWC within water control zone (in.)	0.9	1.2	1.2	
Depletion allowed prior to irrigation (%)	50	50	50	
Maximum net water allowed per irrig. (in.)	0.45	0.6	0.6	
Net water applied per irrigation (in.)	0.45	0.6	0.6	
Max. recommended application rate (in./hr.)	0.8	0.8	0.8	
System efficiency (%)	70	70	70	
Gross application per irrigation (in.) 1/	0.64	0.86	0.86	
Peak irrigation interval (days)	1.8	2.0	2.0	
Irrigation Period (days per irrig.)	1.8	2.0	2.0	
Hours operating per day	20	20	20	
Q_R = Quantity of water required (gpm) 1/	225	390	662	
8. Irrigation Unit Design				
Q_A 2/ = Quantity of water actual (gpm)			675	
Application rate (in./hr) 3/			0.62	
Travel Speed (ft/min) 4/ — Lane Spacing, 290 ft			4.34	
Travel Speed (ft/min) 4/ — Lane Spacing, ft				
Time per 660' run (hrs) — Lane Spacing, 290 ft			2.53	
Time per 660' run (hrs) — Lane Spacing, ft				

9. Sprinkler Specifications:

a. Lane Spacing 290 ft

b. Nozzle Size 1 7/8 in. ring or taper (circle); Wetted Diam. 470 ft; Capacity 675 gpm @ 80 psi; Trajectory Angle 27 degrees; Degrees of coverage 270

c. No. of sprinklers operating simultaneously 1

d. Total design capacity all sprinklers 662 gpm

1/ $Q_R = \dfrac{453 \times 68 \text{ acres} \times 0.86 \text{ in. gross application}}{20 \text{ hrs opr. per day} \times 2 \text{ days per irrigation}} = 662$ gpm

2/ Q_A must be $\geq Q_R$

3/ Application rate = $\dfrac{13630 \times \text{sprinkler gpm}}{(\text{radius of wetted circle})^2 (\text{Degrees of coverage})}$

4/ Travel Speed = $\dfrac{1.605 \times \text{sprinkler gpm}}{\text{Lane Spacing, ft, } \times \text{ gross water applied, in.}}$

TRAVELING GUN IRRIGATION SYSTEM

Cooperator: J. Farmer Designed by: W. Jones Checked by: J. Stone

10. Determing Total Dynamic Head: (Total main line length 1725 ft.)

Kind of Pipe & SDR, Sch, Class, etc	Pipe Size (in.)	Design Capacity (gpm)	IPS: ✓ PIP: PIPE SIZING Length (ft)	Friction Head Loss 5/ (ft/100 ft)	HOSE SIZING 6/ Length (ft)	Friction Head Loss (ft/100ft)	Total Head Loss (ft)	(psi)	Working Pressur Recom-mended max 7/ (psi	Ac Ma (p
PVC, SDR26 Class 160	8	675	1725	0.69	—	—	11.9	27.5	115.	1(
Lay Flat Hose	5	675	—	—	660	4.62	30.5	13.20	—	-
Hose Inlet Pressure 8/ or either Sprinkler Pressure at Nozzle (circle which)							184.8	80.0		
Misc. & Fitting Losses (usually 3 psi ±) 9/							6.9	3.0		
Elevation Difference 10/							15.0	6.49		
Pump Discharge Pressure @ (Main Pipeline Inlet)							249.1	107.84		
Pump Lift (Including losses)							19	8.23		
Total Dynamic Head, TDH							268	116		
Estimated Net Positive Suction Head Available, NPSHA							12.0	—		

11. Pump Requirements:
    Capacity 675 gpm @ 116 psi or 268 ft of head
    and NPSH less than 12 ft

12. Power Unit Requirement:

$$\text{BHP} \geq \frac{675 \text{ gpm} \times 268 \text{ ft TDH}}{3960 \times 0.7 \text{ pump eff.} \times 1.0 \text{ drive eff.}} = 65.3$$

5/ Keep velocity ≤ 5 fps unless means to limit surging and water hammer are otherwide adequate.

6/ Omit this section if required hose inlet pressure is known and is used in TDH calculations.

7/ For plastic pipe 72 percent of the pressure rating unless means to limit surge and water hammer are otherwise adequate.

8/ Mfg. recommended pressure plus one-half the elevation difference (plus or minus) from hose inlet to highest point in the field along the lanes.

9/ Traveler turbine losses (approx. 10 psi) would need to be added as applicable.

10/ Difference in elevation either from well or pump discharge and the elevation of the highest hose inlet or nozzle (plus or minus) in the field along the lanes.

Design Approved By: J. Stone, A. Eng. Date 6/2/86

CHAPTER 10-C. CENTER PIVOT IRRIGATION SYSTEMS

GENERAL

The example problems in this chapter are intended to illustrate the procedure used in the design of center pivot irrigation systems. It is understood that these two examples cannot show all design situations or all alternatives to consider when designing a center pivot irrigation system. Most often center pivot irrigation systems are designed by the manufacturer and evaluated by the engineer.

DESIGN CRITERIA

Design criteria for center pivot irrigation systems are contained in the Technical Guide, Irrigation System, Sprinkler, Code 442, for South Carolina. All center pivot systems must be designed in accordance with applicable requirements contained in Code 442.

FORMULA USED IN DESIGN AND EVALUATING CENTER PIVOT IRRIGATION SYSTEMS

The following formulas are used in the design and evaluation of center pivot irrigation systems:

a. Total capacity requirements based on known application depth, area and time of application.

$$Q = \frac{453\ Ad}{FH}$$

Where: Q = Total system discharge capacity in gpm
A = Acreage of the design area to be sprinkler irrigated in acres.

d = Gross depth of application in inches.
F = Number of days allowed for completion of one irrigation.
H = Number of actual operating hours per day

b. Application rate from center pivot systems.

$$I = \frac{96.3\ Qs}{S_B\ D}$$

Where: I = Average application rate in inches per hour
Qs= Discharge from individual sprinkler in gpm
D = Wetted diameter of sprinkler nozzle in feet
S_B= Spacing of nozzles along the boom in feet
96.3= Units conversion constant = (12 in/ft)(60 min/hr) ÷ (7.48 gal/cu.ft.)

c. Gross application depth in inches from individual sprinklers on a center pivot.

$$d = \frac{Qs}{0.62\ S_\beta\ v}$$

Where : d = Application depth in inches (gross)
v = Velocity of rotational speed of individual sprinkler around the pivot point in feet per minute
0.62 = Units conversion constant = 7.48 gal/ft^3 divided by 12 in./ft.

d. Equations b. and c. can be combined to relate terms into a relationship sometimes useful.

$$v = \frac{D\ I}{60\ d}$$

e. End gun discharge, q_g (gpm)

$$q_g = Q\ (1-(L^2/R^2))$$

Where: L = the length of the lateral pipe (ft)
R = L plus 90 percent of the radius wetted by the end gun (ft)
Q = total system capacity (gpm)

EXAMPLE PROBLEM

The following example illustrates a typical problem. Since center pivots are designed by the manufacturer using computers, this example could apply to many situations in which SCS merely would be providing soils and other data or either could be evaluating a system design. SCS could provide data sheets partially completed to the landowner.The landowner then could have an irrigation company provide pertinent design data on the forms and return them to SCS. An SCS employee then ·ould complete the data sheets as a permanent record for future ·erence and provide copy to the landowner.

185 acres corn.

·g, South Carolina

·sel.

7. Slope: 0-6%.

8. End gun will not be used for this system.

Solution:

The item numbers mentioned in the step by step solution refer to the items on the standard form "Irrigation Data Sheet" in Exhibit 10-C-1.

Step 1. Complete Items 1-4. These items provide pertinent data of the site.

Step 2. Complete Item 5. Make a drawing to scale of the field locating trees, buildings, well and other features.

Step 3. Complete Item 6. Guidance in selecting the moisture extraction rooting depths (soil moisture control zone) and the design peak use rate are to be taken from Tables 3-1 and 4-1 respectively. The weighted AWC is computed using data from Item 1.

Step 4. Complete the following parts of Item No. 7.

a. Available water capacity (AWC) within the water control (root) zone is the product of the root zone moisture extraction depth (24 in.) times the AWC of the soil (0.05 in./in.)
AWC = 24 in. x 0.05 in./in. = 1.20 in.

b. The percent depletion allowed prior to irrigation is selected to be 50%.

c. The maximum net water allowed per irrigation is the product of percent depletion allowed prior to irrigation (50%) times the available water within the root zone (1.20 in.). The maximum net water allowed = 0.50 x 1.20 in. = 0.60 in.

d. The net water to be applied should be less than or equal to the maximum allowed. Use the maximum for this example - 0.6 inches.

e. Maximum application rate from Table 2-6 for sand, 0.6" water applied, & 5% predominate maximum slope = (No limit).

f. The system efficiency is assumed to be 70%.

g. Gross water applied per irrigation is the net water applied (0.60 in.) divided by the system efficiency (0.70). Gross water applied = 0.60 in. / 0.70 = 0.86 in.

h. The peak irrigation interval is the net water applied (0.60 in.) divided by the design peak use rate (0.30 in./day)= 2.0 days.

i. The irrigation period to be used in the formula for determining Q_R is the irrigation interval 2.0 days.

j. The hours operating per day is 22 hours.

k. The quantity of water required (gpm) is computed using the formula:

$$Q_R = \frac{453 \times \_\_\_ \text{ acres} \times \_\_\_ \text{ inches gross application}}{\_\_\_ \text{ hours operating per day} \times \_\_\_ \text{ days per irrigation}}$$

$$Q_R = \frac{453 \times 145 \text{ acres} \times 0.86 \text{ in.}}{22 \text{ hrs/day} \times 2.0 \text{ days/irrigation}}$$

$$Q_R = 1{,}284 \text{ gpm}$$

The manufacturer used 1,300 gpm for the design of the system.

Step 5. The manufacturer provides the data for Item No. 8. This must meet the criteria previously discussed.

a. Pivot length = 1,360 ft(outside tower = 1330 ft); pivot inlet pressure = 65 psi.

b. Impact sprinklers.

c. Gross application per revolution is 0.86 in. per 44 hours.

d. Nozzle gpm and pressure along last 100 ft of span is 10.1 gpm at 45 psi on spacing of 6.4 ft.

e. Nozzle wetted diameter is 102 feet.

f. Gun coverage = ______ft; ____gpm @ ___psi (Not applicable to this problem)

Step 6. Check the maximum application rate, Item 9.

a. Time per revolution to apply gross application = 44 hrs (from manufacturer).

b. Velocity of outside tower:

$$v, \text{ ft/hr} = \frac{\text{outside circumference, ft}}{\text{hours per revolution}}$$

$$= \frac{(2)\ (3.14)\ (1330)}{44 \text{ hours}} = 190 \text{ ft/hr}$$

c. Determine time of application (i.e., time it takes the sprinkler to move past one point), average, and maximum application rates using the formulas provided in item 9.

Step 7. Complete Item 10. for sizing the mainline, determining total dynamic head and the net positive suction head required for the pump.

a. The mainline is 30 feet of 10-inch diameter PVC pipe (SDR 21). The friction head loss is 0.88 ft/100 ft and is taken from Appendix C. The total head loss in the mainlin is 0.88 ft/100 ft x 30 ft = 0.3 ft. The recommended maximum working pressure in the pipe is 0.72 x 200 (class rating)= 144 psi since it is assumed special means to control surge and water hammer will not be provided. The actual working pressure will be computed later in the problem.

b. The pressure at the pivot was given by the manufacturer and is 65 psi. The elev. increase from pivot inlet to highest sprinkler at high point along the lateral = 15 ft. or 6.5 psi. Therefore, the recommended pressure at pivot inlet = 65 + 6.5/2 = 68.2 psi.

c. The miscellaneous and fitting losses were estimated to be 3.0 psi.

d. The elevation difference from well to the pivot inlet was measured to be 12.0 feet.

e. The sum of a., b., c. and d. gives a pump discharge pressure at the main inlet pipe required of 176.7 ft or 76.5 psi. Enter this value also as the actual maximum working pressure in the main. The working pressure is less than the recommended maximum thus the pipe should be adequate.

f. The elevation pumping lift (from item 3) is 150 ft. Total lift including pump column and other losses would be slightly more. Use 150 ft as approximation for lift plus losses.

g. The total dynamic head is the pumping lift plus the pump discharge pressure, 150.0 ft + 176.7 ft = 326.7 ft or 141.4 psi.

h. The minimum net positive suction head available (NPSHA) is approximately equal to 31.0 - h_f + z. (see example in section 10-A for definition of values and Chapter 6 of this guide).
h_f = (use 3 ft for loss at impeller and in the well pipe)
z = 180-150 = 30 ft.

Therefore, NPSHA $\cong$ 31.0-3.0 + 30. = 58.0 ft

Step 8. Complete item 11, Pump Requirement. This is the maximum gpm the pump must produce at a given TDH. From Item 7, the actual Q for the irrigation unit is 1300 gpm. The TDH from the preceeding section is 141 psi or 327 ft. The NPSH required must be less than 58.0 ft (usually this value is most critical for centrifugal pumps).

Step 9. Complete item 12, Power Requirement, using formula given.

Step 10. Complete the plans. The specifications, location of the pipe, check valve, air vents, pressure relief valves, etc., should be shown on the plans.

CONSTRUCTION REQUIREMENTS

Once a system is designed it must be installed as planned in order for it to function properly. The following is a list of key points that should be checked during construction to be assured of a quality installation:

a. Depth of cover over the buried mainline is important for protection from vehicular traffic and farming operation.

b. Thrust block dimension and location to prevent pipe joint separation.

c. Location and size of air vents and pressure relief valve.

d. Size and proper direction of installed check valve.

e. Riser material and dimension as well as location for pivots.

f. Length and quality of pipe, diameter, location, appropriate ASTM designation, size, pressure rating and SDR as measured or found written on the pipe.

g. Determine if IPS or PIP pipe is used which will have an effect on the total head loss of the system.

h. Verify length of the center pivot lateral and if spray or impact type sprinklers.

LAYOUT CONSIDERATIONS

During planning and layout of a center pivot there are many things to be considered. Items to be considered are the soil limitations, obstacles such as fences, ponds, ditches and trees, topography of the field, the farming operation and safety hazards such as electrical and buried gas lines.

The soil limitations might affect the pivot's ability to traverse the field and/or the runoff erosion potential from high application rates.

Obstacles, if not considered, could result in severe damage to the pivot. Bridges or culvert crossings may be needed to cross wet areas or ditches. Electrical lines and buried cable or gas lines must be located prior to burying the pipe or locating the pivot, not only to facilitate installation, but to prevent a real safety hazard.

Topography must be considered because center pivots are limited as to the slope on which they can function properly.

The greater the land slope the greater the erosion potential. Therefore, the application rate must be compatible with the slope to prevent erosion from center pivot systems.

Procedure

For

Determining Gross Application of Center-Pivot Sprinkler

Objective

To develop a table that relates the dial setting of the center-pivot timer to the gross water (in inches) applied. The table may be used by the irrigator to adjust the system speed to obtain a desired gross application. The procedure described applies to electric system timers which read from 0 to 100 percent. However, the procedure can be adapted to other timers.

Procedure

1. Determine Speed of End Tower

Select a reference mark on a wheel on the end tower. Set a stake by this mark. Start timing when the wheel starts moving forward. Continue timing until the wheel has moved 20 to 30 feet or until after the can catch is made. Mark distance traveled by placing a second stake by reference mark on wheel ans stop timing just as the wheel starts to move forward. Read time and measure distance between the two stakes.

$$\text{Speed of end tower, ft per hr} = \frac{\text{Distance traveled, ft} \times 60}{\text{Time, min}}$$

2. Determine Time Per Revolution

Once speed is determined, compute time of travel for one revolution at the % setting on the timer.

$$\text{Time per revolution, hrs (At \% setting on timer)} = \frac{\text{Distance traveled by end tower, ft}}{\text{Speed of end tower, ft per hr}}$$

Distance traveled by end tower, ft =
2 x 3.14 x Distance from pivot to end tower, ft

3. Determine Hours Per Revolution For 100% Dial Setting

$$\text{Hours per revolution (at 100\%)} = \frac{\text{(Hours per revolution)(Dial Setting)}}{100}$$

Note: Use the dial setting on the control panel at the time the speed was determined and hours per revolution corresponding to this setting.

4. Determine Hours Per Revolution For Each Dial Setting

$$\text{Hours per revolution at X\%} = \frac{\text{(Hours per revolution at 100\%) } 100}{\text{X\%}}$$

5. Determine Gross Application For Each Dial Setting

Gross application, in. =

$$\frac{\text{(Hours per revolution for dial setting)(GPM)}}{\text{(453) (Acres irrigated)}}$$

Note: For acres irrigated, use design acres. If not available, use the effective wetted area.

Example

The center-pivot timer was set on 35% and end tower traveled 60.2 feet in 19 minutes. Distance from pivot to end tower is 1330 feet. System applies 1300 gpm on 145 acres.

End tower speed = $\frac{(60.2)(60)}{19}$ = 190 ft per hr

Time per revolution at 35% = $\frac{(2)(3.14\ )(1330)}{190}$ = 44 hrs

Hours per revolution at 100% = $\frac{(44)(35\%)}{100}$ = 15.4 hrs

Hours per revolution for each of the other dial settings:

For 90% = $\frac{(15.4)(100)}{90}$ = 17.1 hrs

For 80% = $\frac{(15.4)(100)}{80}$ = 19.2 hrs

For 70% = $\frac{(15.4)(100)}{70}$ = 22.4 hrs

For 60% = $\frac{(15.4)(100)}{60}$ = 25.7 hrs

For 50% = $\frac{(15.4)(100)}{50}$ = 30.8 hrs

For 40% = $\frac{(15.4)(100)}{40}$ = 38.5 hrs

For 30% = $\frac{(15.4)(100)}{30}$ = 51.3 hrs

For 20% = $\frac{(15.4)(100)}{20}$ = 77.0 hrs

$$\text{For } 10\% = \frac{(15.4)(100)}{10} = 154.0 \text{ hrs}$$

Gross application for each dial setting:

$$\text{For } 100\% = \frac{(15.4)(1300)}{453\ (145)} = 0.30 \text{ in.}$$

$$\text{For } 90\% = \frac{(17.1)(1300)}{453\ (145)} = 0.34 \text{ in.}$$

$$\text{For } 80\% = \frac{(19.2)(1300)}{453\ (145)} = 0.38 \text{ in.}$$

$$\text{For } 70\% = \frac{(22.0)(1300)}{453\ (145)} = 0.44 \text{ in.}$$

$$\text{For } 60\% = \frac{(25.7)(1300)}{453\ (145)} = 0.51 \text{ in.}$$

$$\text{For } 50\% = \frac{(30.8)(1300)}{453\ (145)} = 0.61 \text{ in.}$$

$$\text{For } 40\% = \frac{(38.5)(1300)}{453\ (145)} = 0.76 \text{ in.}$$

$$\text{For } 30\% = \frac{(51.3)(1300)}{453\ (145)} = 1.02 \text{ in.}$$

$$\text{For } 20\% = \frac{(77.0)(1300)}{453\ (145)} = 1.52 \text{ in.}$$

$$\text{For } 10\% = \frac{(154.00)(1300)}{453\ (145)} = 3.05 \text{ in.}$$

Summary

Dial Setting	Hour/ Revolution
100	15.4
90	17.1
80	19.2
70	22.0
60	25.7
50	30.8
40	38.5
30	51.3
20	77.0
10	154.0

IRRIGATION DATA SHEET

System type (circle): Center Pivot, Traveling Gun, ____________
(Other, list)

CONSERVATION DISTRICT Orangeburg FIELD OFFICE Orangeburg
COOPERATOR Bill Jones LOCATION Orangeburg Co
IDENTIFICATION NO. System 1 FIELD NO. 3

1. Design area 145 acres (Area actually irrigated)
   Soil series Fuguay

   Design Soil Series: Fuguay Predominate maximum slope 5

Soil Depth (in.)	Texture (USDA)	Average AWC (in./in.)
0-24	sand	0.05

2. Crops:

Crop	Acres	Planting Date	Maturity Date
Corn	145	3/20	7/8
Total	145		

3. Water supply:
   Source of supply: (stream, well, reservoir, etc.) 16 inch

   Stream: Measured flow (season of peak use) ______ gpm

   Reservoir: Storage ____ ac. ft. Available for irrigation ______ ac. ft.

   Stream or Reservoir: Maximum drawdown available ______ ft.; Maximum elevation lift on intake side of pump ______ ft.

   Well: Static Water Level 140
   Measured Capacity 1450 gpm @ 10 ft drawdown
   Design Pumping Lift 150 ft (to ground level - main pipeline inlet
   Pump Impeller Level 180

   Distance supply source (main pipeline inlet) to field 0 ft

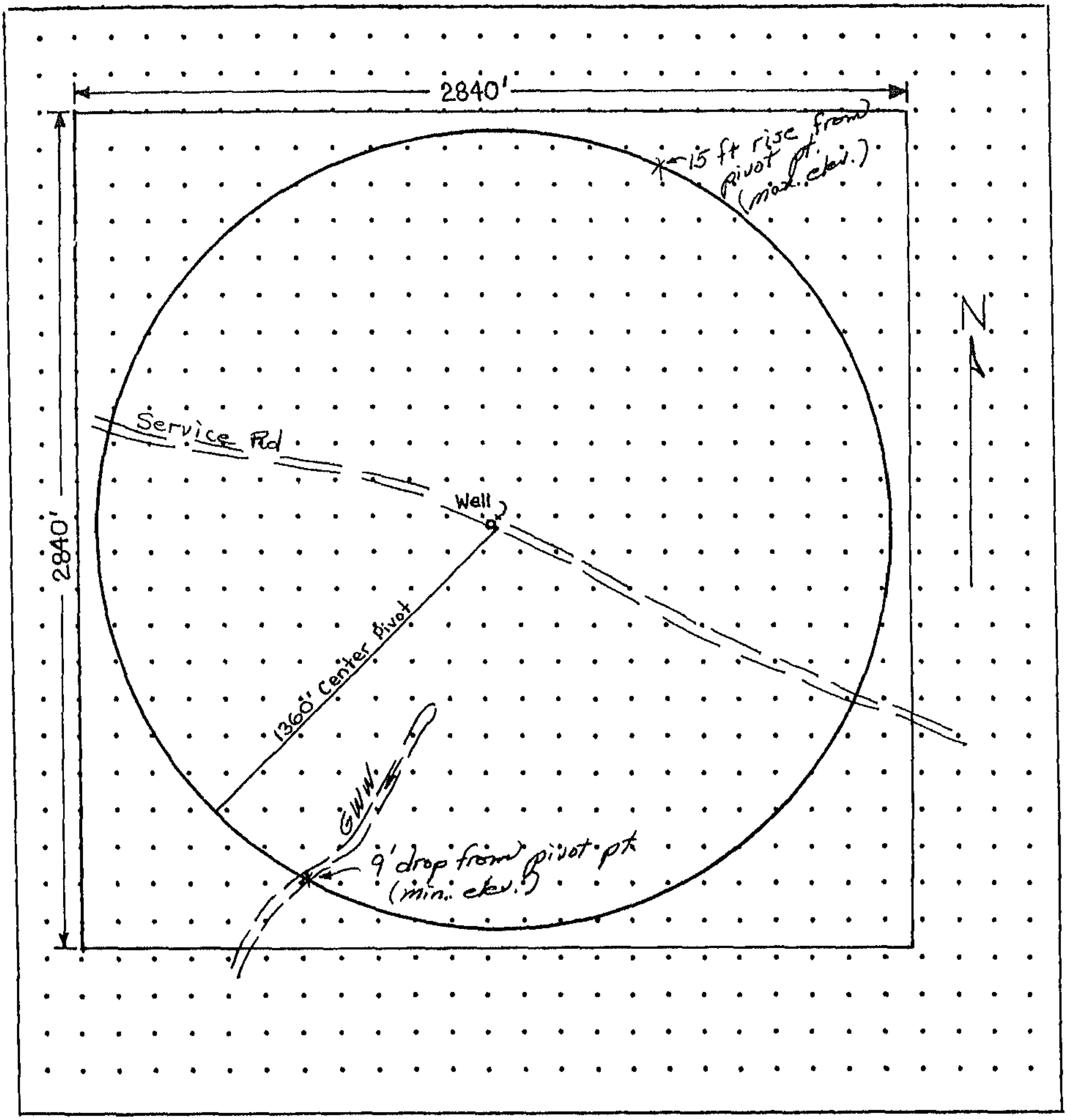
   Quality of water (evidence of suitability): No apparent prob

4. Other Data:
   Type of power unit and pump to be used: Diesel

CENTER PIVOT IRRIGATION SYSTEM

Cooperator: Bill Jones Designed by: Bob Smith Checked by: J. Stone

5. Map of design area - Scale 1" = 500 ft
Sketch map on grid or attach photo or overlay.



Sketch map should show:

a. Source of water
b. Major elevation differences
c. Row direction
d. Sprinkler system layout
e. Plan of operation
f. Field obstructions (gullies, trees, buildings, etc.)
g. North arrow

CENTER PIVOT IRRIGATION SYSTEM

Cooperator: Bill Jones Designed by: B. Smith Checked by: J. Stone

6. Crop and Soil Information	CROP NUMBER 1	2	3	4
Kind of crop	Corn			
Acreage to be irrigated (acres)	145			
Depth of Soil Water Control Zone	24			
Design peak use rate (in./day)	.30			
Weighted AWC for water control zone(in./in)	.05			

7. Design Procedure				
AWC within water control zone (in.)	1.2			
Depletion allowed prior to irrigation (%)	50			
Max. net water allowed per irrigation (in.)	0.6			
Net water applied per irrigation (in.)	0.6			
Max. recommended application rate (in./hr.)	No limit			
System efficiency (%)	70			
Gross application per irrigation (in.) 1/	.86			
Peak irrigation interval (days)	2.0			
Irrigation period (days per irrig.) 1/	2.0			
Hours operating per day 1/	22			
Q_R = Quantity of water required (gpm) 1/	1284			
Q_A = Quantity of water actual (gpm) 2/	1300			

8. Pivot Specifications: 3/

a. Pivot Length 1360 ft(outside tower 1330 ft); Pivot Inlet Pressure 65 psi (Nominal pressure assuming level topography)

b. Spray __ or Sprinkler ✓

c. Gross application per revolution 0.86 in. per 44 hours.

d. Nozzle gpm along last 100' of span 10.1 gpm @ 45 psi on spacing of 6.4 ft

e. Nozzle wetted diameter 102 ft; trajectory-low, medium, or high (circ

f. End gun wetted diam. ___ ft; ___ gpm; ___ psi; Nozzle size ___ inch-ring or taper (circle); Trajectory-low, medium or high (circle) ___ degre

9. Checking Maximum Application Rate:

a. Time (hrs) per revolution to apply gross application = 44 hrs

b. Vel.(V) of end of line = $\frac{\text{outside circum. } 2\pi\ 1330 \text{ ft}}{44 \text{ hrs/revolution}}$ = 190 ft/hr

c. Time of application (hrs) = $\frac{\text{wetted dia. ft}}{\text{V, ft/hr}} = \frac{102}{190} = 0.54$ hr

d. Average application rate, in./hr = $\frac{\text{gross application, in.}}{\text{time of applic., hrs}} = \frac{.86}{.54} = 1.6$ in/

e. Max. application rate ≅ 1.3 x av. applic. rate = 1.3x 1.6 in./hr = 2.1

1/ $Q_R = \frac{453 \times 145 \text{ acres} \times 0.86 \text{ inches gross application}}{22 \text{ hrs opr. per day} \times 2 \text{ days per irrig.}} = 1284$ gpm

2/ Q_A must be $\geq Q_R$

3/ Final specifications to be provided by manufacturer

CENTER PIVOT IRRIGATION SYSTEM

Cooperator: Bill Jones Designed by: Bob Smith Checked by: J. Stone

10. Determining Total Dynamic Head:

Total main line length 30 ft

Kind of Pipe and SDR, Sch, Class, etc	Pipe Size (in.)	Design Capacity (gpm)	IPS: ✓ PIP: __ PIPE SIZING Length (ft)	Friction 4/ Head Loss (ft/100 ft)	Total Head Loss (ft)	Total Head Loss (psi)	Working Pressure Recommended Max. 5/ (psi)	Working Pressure Actual Max. (psi)
PVC, SDR 21 Class 200	10	1300	30	0.88	0.3	0.1	144.	76.5
Needed at Pivot Inlet 6/					157.5	68.2		
Misc. & fitting losses (usually 3 psi +)					6.9	3.0		
Elevation Difference 7/					12.0	5.2		
Pump Discharge Pressure (main pipeline inlet)					176.7	76.5		
Pumping lift (including losses)					150.	64.9		
Total Dynamic Head, TDH					326.7	141.4		
Estimated Net Positive Suction Head Available, NPSHA					58	—		

11. Pump Requirements:

Capacity 1300 gpm @ 141 psi or 327 ft of head and NPSH less than 58 ft.

12. Power Requirements:

$$BHP \geq \frac{1300 \text{ gpm} \times 327 \text{ ft. TDH}}{3960 \times 0.7 \text{ pump eff.} \times \_\_}$$

CENTER PIVOT IRRIGATION SYSTEM

Cooperator: Bill Jones Designed by: B. Smith Checked by: J. Stone

	CROP NUMBER			
6. Crop and Soil Information	1	2	3	4
Kind of crop	Corn			
Acreage to be irrigated (acres)	145			
Depth of Soil Water Control Zone	24			
Design peak use rate (in./day)	.30			
Weighted AWC for water control zone(in./in)	.05			
7. Design Procedure				
AWC within water control zone (in.)	1.2			
Depletion allowed prior to irrigation (%)	50			
Max. net water allowed per irrigation (in.)	0.6			
Net water applied per irrigation (in.)	0.6			
Max. recommended application rate (in./hr.)	No limit			
System efficiency (%) 1/	70			
Gross application per irrigation (in.)	.86			
Peak irrigation interval (days)	2.0			
Irrigation period (days per irrig.) 1/	2.0			
Hours operating per day 1/	22			
Q_R = Quantity of water required (gpm) 1/	1284			
Q_A = Quantity of water actual (gpm) 2/	1300			

8. Pivot Specifications: 3/
   a. Pivot Length 1360 ft(outside tower 1330 ft); Pivot inlet Pressure 65 psi (Nominal pressure assuming level topography)
   b. Spray __ or Sprinkler ✓
   c. Gross application per revolution 0.86 in. per 44 hours.
   d. Nozzle gpm along last 100' of span 10.1 gpm @ 45 psi on spacing of 6.4 ft
   e. Nozzle wetted diameter 102 ft; trajectory-low, medium, or high (circle)
   f. End gun wetted diam. ___ft; ___gpm; ___psi; Nozzle size ___inch-ring or taper (circle); Trajectory-low, medium or high (circle) ___degrees

9. Checking Maximum Application Rate:
   a. Time (hrs) per revolution to apply gross application = 44 hrs
   b. Vel.(V) of end of line = $\frac{\text{outside circum. } 2\pi\ 1330 \text{ ft}}{44 \text{ hrs/revolution}}$ = 190 ft/hr
   c. Time of application (hrs) = $\frac{\text{wetted dia. ft}}{\text{V, ft/hr}} = \frac{102}{190} = 0.54$ hr
   d. Average application rate, in./hr = $\frac{\text{gross application, in.}}{\text{time of applic., hrs}} = \frac{.86}{.54} = 1.6$ in/hr
   e. Max. application rate ≅ 1.3 x av. applic. rate = 1.3x 1.6 in./hr = 2.1 in

1/ $Q_R = \frac{453 \times 145 \text{ acres} \times 0.86 \text{ inches gross application}}{22 \text{ hrs opr. per day} \times 2 \text{ days per irrig.}} = 1284$ gpm

2/ Q_A must be $\geq Q_R$

3/ Final specifications to be provided by manufacturer

CENTER PIVOT IRRIGATION SYSTEM

Cooperator: Bill Jones Designed by: Bob Smith Checked by: J. Stone

10. Determining Total Dynamic Head:

Total main line length 30 ft

Kind of Pipe and SDR, Sch, Class, etc	Pipe Size (in.)	Design Capacity (gpm)	IPS: ✓ PIP: __ PIPE SIZING		Total Head Loss		Working Pressure	
			Length (ft)	Friction 4/ Head Loss (ft/100 ft)	(ft)	(psi)	Recommended Max. 5/ (psi)	Actual Max. (psi)
PVC, SDR 21 Class 200	10	1300	30	0.88	0.3	0.1	144	76.5
Needed at Pivot Inlet 6/					157.5	68.2		
Misc. & fitting losses (usually 3 psi +)					6.9	3.0		
Elevation Difference 7/					12.0	5.2		
Pump Discharge Pressure (main pipeline inlet)					176.7	76.5		
Pumping lift (including losses)					150.	64.9		
Total Dynamic Head, TDH					326.7	141.4		
Estimated Net Positive Suction Head Available, NPSHA					58	—		

11. Pump Requirements:

Capacity 1300 gpm @ 141 psi or 327 ft of head and NPSH less than 58 ft.

12. Power Requirements:

$$BHP \geq \frac{1300 \text{ gpm} \times 327 \text{ ft. TDH}}{3960 \times 0.7 \text{ pump eff.} \times 1.0} \quad \underline{} = 153$$

CHAPTER 10-D. TRICKLE IRRIGATION SYSTEM

GENERAL

The example problem in this chapter is intended to illustrate the procedure to follow in the design of trickle irrigation systems. It is understood that one example cannot illustrate all design situations, site conditions or alternatives to consider when designing a trickle irrigation system.

DESIGN CRITERIA

Design criteria for trickle irrigation systems are contained in the Technical Guide, Irrigation System, Drip, Standard 441. All trickle irrigation systems must be designed in accordance with the criteria contained in Standard 441. Detailed guidelines for design of trickle irrigation system are given in NEH 15, Chapter 7.

EXAMPLE PROBLEM

The following example problem is intended to cover the basic design steps to follow in the design of trickle irrigation systems. A standard form (Exhibit 10-A-1) is used and is a useful tool in designing and in recording data.

Given:

1. Location: Aiken County.
2. Field Shape: 2,640 feet north to south and 1,320 feet east to west (80 acres).
3. Soil: Faceville S.L.
4. Crop: Pecans.
5. Row direction and spacing: north and south.
6. Tree spacing: 50 ft. x 50 ft.
7. Well information: existing 6 in. diameter.
8. Owner would like to operate half the system at one time. Emitter discharge rate preferred is 2 gph.

Solution:

The item numbers mentioned in the step by step solution refer to the items on the standard form "Irrigation Data Sheet" in Exhibit 10-D-1.

Step 1. Complete Items 1-4. These items provide pertinent data of the site.

Step 2. Complete Item 5. Make a drawing to scale of the field locating trees, well, and other features.

Step 3. Complete Item 6. The moisture extraction depth (soil water control zone) for the soil is 24 inches (Table 3-1). The design peak use rate 0.13 inches/day is taken from Chapter 4, Table 4-1 and is denoted by F_n. Note that F_n varies depending upon the value F (see step 5-C following) for orchards.

Step 4. Complete Item 7. The weighted AWC can be computed from item 1 and the permeability rate can be obtained from section II of the Technical Guide or from the county soil survey.

Step 5. Design procedure. Complete the following parts of Item 8.

a. Determine the field area "A" (ft^2 served by "N" emitters). This is determined by the tree spacing which is 50 feet x 50 feet which equals 2,500 ft^2.

b. Determine the design area of the crop for "N" emitters. The design area may be less than 100 percent of the field area but not less than the mature crop root zone area. The mature crop root zone area for the pecans in this example was determined to be .70 x 2500 = 1750 ft^2.

c. The value "F" which is the percent of "A" used for the design area, was determined to be 0.70.

d. Enter the water application efficiency. It is estimated to be 0.90 in this example.

e. Determine the number of emitters for the design area. A rule of thumb is wet a minimum of 25% of the root zone area. In this example, the minimum wetted area recommended would be 0.25 x 1,750 ft^2 = 438 ft^2. The wetted area from one emitter is estimated to be about 12 ft in diameter or about 113 sq ft. Thus the minimum number of emitters based upon area wetted = 438/113 = 3.9. The minimum number of emitters based upon capacity for 12 hours of pumping = (2471/0.9) ÷ [(2x12) x 17.4]= 6.6. Use 8 emitters per tree to allow uniform spacing of emitters along two laterals serving each row of trees (4 emitters per lateral).

f. The preferred discharge rate of emitters, Q, was given as 2 gph.

g. Determine the hours of operation per day, T.

$$T = \frac{F_n AF}{1.604QNE} = \frac{(0.13)\ (2,500)\ (0.70)}{(1.604)(2.0)(8)(0.90)} = 9.8 \text{ hours/day}$$

h. Determine the system capacity. There are 676 trees to be irrigated at one time with eight 2 gph emitters per tree. Therefore, the system capacity is:

$$\frac{676 \text{ trees} \times 8 \text{ emitters} \times 2 \text{ gph emitters}}{60 \text{ min/hr}} = 180 \text{ gpm}$$

Step 6. Complete Item 9. Select an emitter that will provide a flow rate of 2.0 gph. When selecting an emitter, a flow chart for the emitter should be obtained. Lateral lines normally are so designed that when operating at design pressure the discharge rate of any emitter served by the lateral will not exceed a variation of $\pm$ 10 percent of the design discharge rate (Technical Guide Standard 441-minimum variation = 15%).

The flow chart for the emitter selected in this example (2 gph @ 15 psi) has flow rate variations and corresponding pressure variations as follows (see similar flow chart for a 1.0 gph emitter in Chapter 5, Figure 5-6):

2.0 gph + 10% = 2.2 gph @ 17.5 psi
2.0 gph - 10% = 1.8 gph @ 12.5 psi

This allowable variation can be entered in the appropriate part of Item 11.

Step 7. Complete Item 10. The procedure for determining total dynamic head and net positive suction head available is similar to that described for sprinkler irrigation in Chapter 10-A. The pipe sizing data sheet was used to compute the friction loss in this example. Friction loss tables are included in Appendix C. The topography was gently sloping so elevation differences were included in the calculations.

The design emitter pressure was determined in Step 6.

The filter selected should be based on water quality and manufacturer's recommendations. The pressure loss in this example was based on manufacturer's literature.

The NPSHA $\cong 31.0 - h_f + z \cong 31.0 - 3 + 20 = 48.0'$

23.1 psi - 1.0 psi (misc. loss) - 5.0 psi (filter loss) - 3.3 psi (submain loss) - 0.8 psi (lateral loss) = 13.0 psi. This is greater than the minimum allowable of 12.5 psi.

Step 11. Complete the plans. Include as needed: a chlorinator, check valves, pressure regulators, pressure relief valves, combination air vacuum valves, flow meters, gate valves, etc.

MATERIAL AND CONSTRUCTION REQUIREMENTS

Construction shall be done to the lines and grades determined by the design and the equipment and materials shall be of type, size and quantities specified in the plans. The installing contractor will be responsible for the proper installation of the system.

Emitters shall be installed as recommended by the manufacturer. Trenches excavated for pipe placement shall have a straight alignment. The width of the trench at any point below the top of the pipe shall be no wider than is necessary to lay, join, and backfill the pipe and in no event be more than 18 inches wider than the diameter of pipe. The buried pipe shall have a settled minimum cover as specified in the appropriate technical guides. All joints and connections involved in the installation of the pipe shall be made in accordance with the pipe manufacturer's recommendations and shall be constructed to withstand the maximum design working pressure for the pipelines without leakage. The quality of the pipe placed underground shall equal or exceed the quality requirements specified in the appropriate Technical Guides. Pipe placed above ground shall be as recommended by the manufacturer.

The filter system shall be of such that flushing, cleaning or replacement can be performed as required without introducing contaminants or foreign particles into the system. All injectors, such as fertilizer injectors, shall be installed upstream of the filter system, except for injectors equipped with separate filters.

Pumps, power units and filters shall be set on a firm base and be placed in proper alignment. All pertinent safety codes and manufacturer's recommendations shall be met.

Once completed, the system shall be tested for operating pressures, strength, leakage and satisfactory operation. During the initial start up, the lateral lines shall be flushed to remove any sediment or foreign materials before placement of end plugs.

The installing contractor or material supplier shall furnish the owner with written certification that pipe installed below ground will comply with the applicable standards referred to in the Technical Guides. The owner shall also be furnished a written guarantee by the contractor protecting the owner against defective materials and workmanship over a period of not less than one year after completion of all work covered under the contract.

IRRIGATION DATA SHEET

System type (circle): Center Pivot, Traveling Gun, Drip
(Other, list)

CONSERVATION DISTRICT Aiken
COOPERATOR Robert Smith
IDENTIFICATION NO. Units 1 & 2

FIELD OFFICE Aiken
LOCATION Aiken Co.
FIELD NO. 1

1. Design area 80 acres (Area actually irrigated)
   Soil series Faceville

   Design Soil Series: Faceville   Predominate maximum slope <1 %

Soil Depth (in.)	Texture (USDA)	Average AWC (in./in.)
0-6	S. Loam	0.075
6-75	S. Clay	0.15

2. Crops:

Crop	Acres	Planting Date	Maturity Date
Pecans	80	—	—
Total	80		

3. Water supply:
   Source of supply: (stream, well, reservoir, etc.) 6" Well

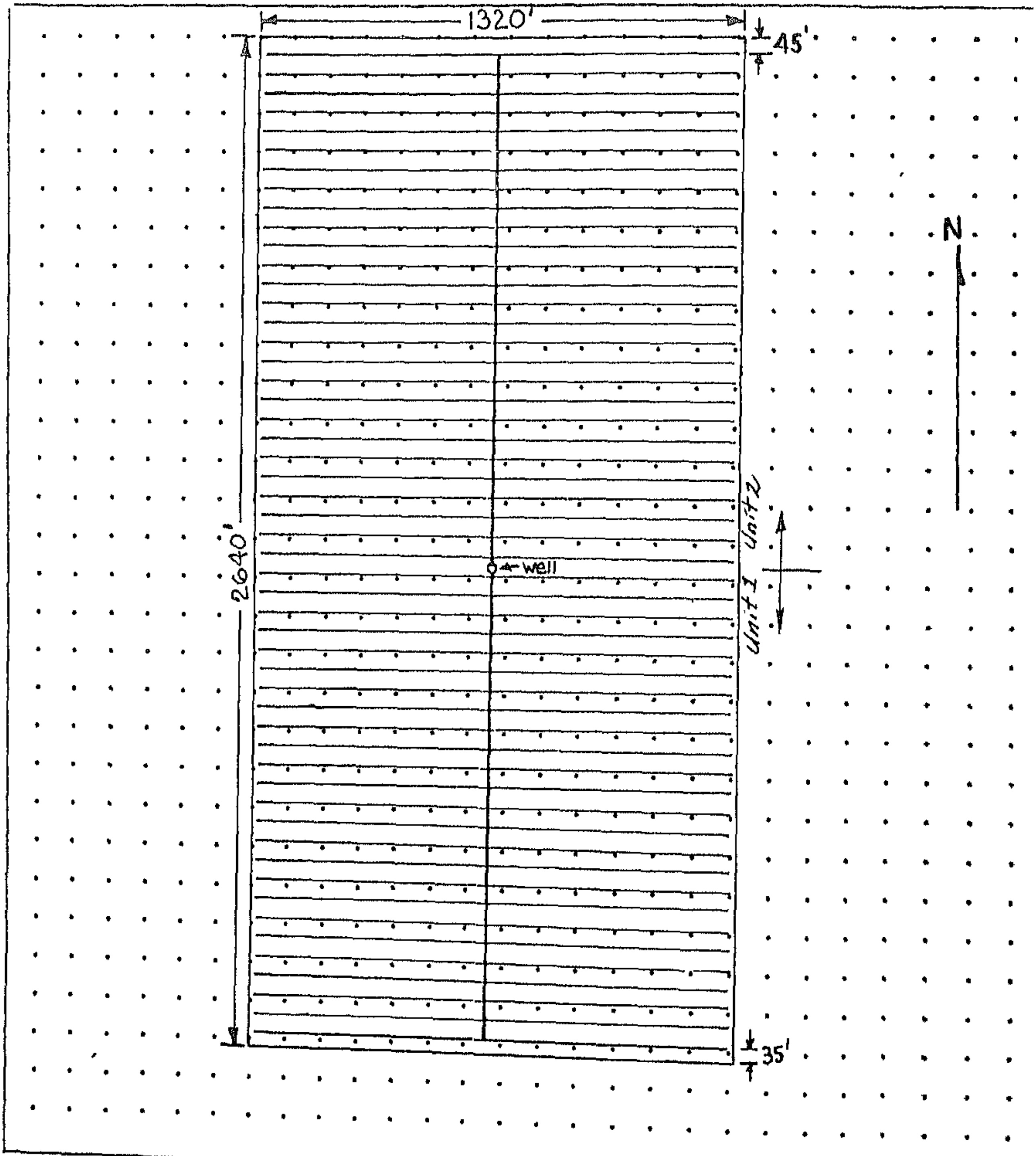
   Stream: Measured flow (season of peak use) ________ gpm

   Reservoir: Storage ____ ac. ft. Available for irrigation _____ ac. ft.

   Stream or Reservoir: Maximum drawdown available ____ ft.; Maximum elevation lift on intake side o

Cooperator: Robert Smith Designed by: J. Jones Checked by: J. Stone

5. Map of design area - Scale 1" = 400 ft
Sketch map on grid or attach photo or overlay.



Sketch map should show:

a. Source of water
b. Major elevation differences
c. Row direction
d. Sprinkler system layout
e. Plan of operation
f. Field obstructions (gullies, trees, buildings, etc.)
g. North arrow

TRICKLE IRRIGATION SYSTEM

Cooperator: R. Smith Designed by: J. Jones Checked by: J. Stone

6. Crop Information	IRRIGATION UNIT NUMBER 1	2	3	4
Kind of crop 1/	Pecan	Pecan		
Acreage to be grown (acres) 1/	40	40		
Soil Water Control Zone (in.)	24	24		
Peak use rate (in./day), F_n	.13	.13		

7. Soil Information	1	2	3	4
Weighted AWC for rooting depth (in./in.)	0.13	0.13		
Permeability (in./hr)	0.6 - 2.0	0.6-2.0		

8. Design Procedure	1	2	3	4
"A" field area served by N emitters (ft^2)	2500	2500		
Design area of crop for N emitters (ft^2)	1750	1750		
"F"-% of "A" used for design area(decimal)	0.70	0.70		
"E"- water application efficiency (decimal)	0.9	0.9		
"N"- number of emitters for design area	8	8		
"Q"- discharge rate of emitter (gph)	2	2		
"T"- hours of operation per day(18 hrs max) 2/	9.8	9.8		
System capacity (gpm) = $\frac{\text{"N" per irrigation unit X "Q"}}{60}$	180	180		

9. System Specifications

a. Emitter spacing ≈ 12.5 ft, lateral spacing 50 ft (dual laterals, each ≈ from tree row)

b. Emitter capacity 2 gph @ 15 psi

c. Max. length lateral 650 ft, size 3/4 in., Number of emitters 52

d. Total number laterals 208; Number operating simultaneously 104;

e. Total number of emitters 10816

1/ For orchards, list tree spacing and canopy area.

Tree spacing 50 ft by 50 ft

Canopy area 1750 ft^2 [assumed to be the root (design) area]

2/ Use the following formula:

$$T = \frac{F_n A F}{1.604\ QNE}$$

TRICKLE IRRIGATION SYSTEM

Cooperator: R. Smith Designed by: J. Jones Checked by: J. Stone

10. Determining Total Dynamic Head 3/

Kind of Pipe			Design Capacity (gpm)	IPS PIP Other___ Diameter (in.)	Length (ft)	Friction Head Loss 4/ (ft/100ft)	Total Head Loss HL (ft)	Total Head Loss, HL		Working Pressure
Main	Sub-Main	Lateral						(ft)	(psi)	Recommended Max 5/ (psi)
XXXX		✓	(see sh. 5 of 5)					XXXX	XXXX	57.6
XXXX	✓							XXXX	XXXX	115.
XXXX								XXXX	XXXX	
XXXX								XXXX	XXXX	
XXXX								XXXX	XXXX	
XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	9.62×0.5 =	4.8 6/	2.1	
—	XXXX	XXXX					XXXX	0	0	
	XXXX	XXXX					XXXX			
	XXXX	XXXX					XXXX			
	XXXX	XXXX					XXXX			
	XXXX	XXXX					XXXX			
Design Emitter Pressure								34.6	15.0	
Friction Loss in filter System								11.6	5.0	
Miscellaneous Losses								2.3	1.0	
Pump Discharge Pressure (at entrance to submain)								53.4	23.1	
Pumping Lift (including losses)								120.	51.9	
Total Dynamic Head, TDH								173.4	75.0	
Estimated Net Positive Suction Head Available, NPSHA								48'	—	

11. Pump Requirements: 180 gpm @ 75.0 psi or 173 ft of head and NPSH less than 48 ft.

12. Power Unit Requirement:

$$\text{BHP} \geq \frac{180 \text{ gpm} \times 173 \text{ ft TDH}}{3960 \times 0.7 \text{ pump eff.} \times 1.0 \text{ drive eff.}} = 11.2$$

13. Check allowable pressure variation that will provide a ± 10% flow rate
    Allowable = 12.5 psi to 17.5 psi (Taken from manufacturer's curve)
    7/ Actual = 13.0 psi to 17.0 psi

14. Remarks

3/ Use pipe sizing data sheets where elevation differences are present and/or additional data lines needed.

4/ Keep velocity ≤ 5fps unless means to control surge and water hammer are otherwise adequate.

5/ For plastic pipe, pressure rating divided by 0.72 unless means to control surge and water hammer are otherwise adequate.

6/ Sets optimum nozzle pressure at a theoretical mid-system sprinkler.

7/ Consider elevations and location. Adjust 6/ if possible to stay within allowed variation. If not, the system must be redesigned.

Design approved by: ______________________ Date: ____________

PIPE SIZING DATA SHEET

Sheet 5 of 5

Cooperator R. Smith
Field Office Aiken

Designed by J. Jones
Checked by J. Stone

Irrigation Unit No. 1			Pipe Sizing Calculations								Pipe Material ___, SDR ___ IPS ✓ PIP ___ Other ___
Main	Sub-Main	Lateral	Design Capacity (gpm)	Pipe Diam. (in.)	Length (ft)	HL_f (ft/100')	Multiple Outlet Factor	Total HL_f (ft)	Elevation Difference HL_e (ft)	Total HL HL_f+HL_e (ft)	REMARKS
		✓	1.73	3/4	650	0.37	.361 1/	0.87	1.0	1.87	PE Pipe, SDR 17, Class 80
	✓		180.	5	1300 4/	0.50	.356 2/	+2.31	1.5	3.00	PVC, SDR 26, Class 160
	✓		125.	5	900 5/	0.25	.358 3/	-0.81			
	✓		125.	4	900	0.73	.358 3/	2.35	2.4	4.75	
										Σ 9.62	

1/ 52 outlets
2/ 104 "
3/ 72 "
4/ Actual length of 5" dia. = 400'
5/ This length entered for computations only.

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 11. IRRIGATION WATER MANAGEMENT

CONTENTS

Figures

Exhibits

CHAPTER 11. IRRIGATION WATER MANAGEMENT AND EVALUATION PROCEDURES

GENERAL

Irrigation water management is the act of timing and regulating irrigation water applications in a way that will satisfy the water requirement of the crop without the waste of water, soil, or plant nutrients. It means applying water according to crop needs, in amounts that can be held in the soil and available to crops, and at rates consistent with the intake characteristics of the soil and the erosion hazard of the site.

Management is a prime factor in the success of an irrigation program. The system may be of the best possible design with equipment that is up-to-date and efficient, but success is still not insured.

Labor requirements for a hand-moved irrigation system are large. Often the equipment has to be operated at the same time other labor demands are at their peak. Solid-set and mechanically-moved systems require very little labor. The irrigator must carefully consider how the operation of his type of irrigation system will fit into the total farming enterprise. He must be sure that he has the manpower available for his choice of irrigation system. Good planning and utilization of labor are essential.

Large quantities of water are required for irrigation. Therefore, efficient use of water should be the goal of an adequate program of irrigation system management. Benefits from investments in the irrigation system, labor and irrigation water, are derived from improved quality, yield and marketing advantages that can be achieved from irrigated crops. To obtain these benefits with efficient water use, the irrigator must answer three very pertinent questions: When should I irrigate, how much water should I apply, and is the irrigation system functioning properly?

Man irrigators tend to delay irrigation in hope that rain will come. A cardinal rule of the irrigator must be that he keeps his eyes on the soil and plants and not on the sky. If drainage is adequate, no serious problems should develop should rainfall occur after the completion of proper irrigation.

The question "When should I irrigate?" cannot always be answered precisely. No set rule applies to all situations. Several factors must be considered in each individual case, such as the particular crop, stage of crop growth, minimum practical amount of water to apply, available water supply, irrigation system capacity, and other farm operations schedules.

Most crops should be irrigated by the time that half of the available moisture in the crop root zone has been used. Some crops, however, are thought to do better at higher or lower moisture levels at time of

irrigation than other crops (see Chapter 3, Irrigation Needs of Particular Crops Section). An irrigation may be needed before half of the available moisture has been used. The need for irrigation could be doubtful for any crop until the soil moisture deficit approaches one-third of the available moisture holding capacity of the crop root zone. With these considerations in mind, unless otherwise noted, a good general rule is to commence irrigation for row crops when the soil moisture deficit reaches about the forty percent level for fine to medium textured soils and about fifty percent for moderately coarse to coarse textured soils. Some special purpose irrigations, such as for seed germination, are exceptions to this general rule. Also vegetable crops normally should be irrigated at least by the time 40% of the available moisture is depleted.

It is not always practical and probably not desirable to maintain the same soil moisture level throughout the growing season. Aside from moisture needs to ensure a stand, most crops have critical periods during the growing season when good soil moisture levels must be maintained to obtain high quality yields. The critical period for most crops occurs during the part of the growing season of pod, fruit, tuber, or ear formation and development. Chapter 3, Table 3-2, lists the critical growth periods for a number of important crops.

If sufficient growing season exists for the desired development of the crop, short periods of low moisture during the early part of the growing season may not be harmful except for leaf or forage crops. However over-stimulation of vegetative growth from a combination of high soil fertility and available soil moisture can also be objectionable. This may delay time of harvest enough to miss the period of highest fresh market demand, affect the grade for processing, or cause losses in late maturing crops from frost damage. If irrigation water supplies are limited, the best use of the irrigation water supply would be during the critical growth period of the crop.

Irrigation must begin in time so that the irrigated area can be covered before the available moisture level in the last portion of the field to be irrigated reaches a point to cause unfavorable moisture stress of the crop.

Irrigation schedules often can be varied somewhat to fit other operation schedules. Many times the irrigation system is utilized on a diversity of crops which are at different stages of growth. When the available soil moisture level for each crop area is known, the timing of irrigations can be varied. For example, irrigations of a particular crop may be moved ahead a day or two to facilitate application of insecticides or herbicides.

In determining the need for irrigation one must not overlook the fact that some portions of the field may be drier than others. Poor water distribution during a previous irrigation may cause the soil moisture deficiency in one portion of the field to be considerably greater than in other parts of the field; also, the soil in one part of the field may have less available moisture holding capacity than the soils in

another part. The moisture in this soil might be depleted to the 50 percent level long before the other soils approach that level. If these kinds of critical areas are of significant size, the decision as to when to irrigate should be based on the available moisture in the drier areas.

IRRIGATION EVALUATION

The effectiveness of a farmer's irrigation water management practices can be determined by making field observations and evaluations. These observations and evalations should also be used to determine if the values and assumptions that were used in the planning and design of the systems conform to the actual field conditions. The results of these observations and evaluations are used to help the irrigator improve his water management techniques and/or upgrade his irrigation system. Procedures for evaluating irrigation systems are not addressed in this chapter but are covered in detail in Appendix B.

IRRIGATION SCHEDULING

The amount of crop evapotranspiration or water requirement varies according to climatic conditions and crop growth stage. The rate of evapotranspiration is much less during the winter season than in the summer. Likewise, the rate is much less when a crop just begins to grow than it is as the crop reaches maturity.

The determination of when and how much to apply requires a knowledge of the available water capacity (AWC) of the soil, the crop rooting depth, the management allowed deficit (MAD) or plant stress level for the specified crop, the crop consumptive use, and the critical periods in the growing season when the crop should not be stressed.

SOIL MOISTURE MEASUREMENTS

The amount of moisture remaining for crop use in found by making soil moisture measurements. The moisture level can be estimated by the feel and appearance method, as well as by various soil moisture measuring devices. Moisture measurements can be used alone for scheduling irrigations, but usually are used in combination with consumptive use prediction methods to reduce the number of moisture measurement needed.

Also, one or more days lead time may be needed by the irrigator to plan farming operations or make other management decisions prior to irrigating. He may not be able to wait until a moisture measurement reveals it is time to irrigate.

The consumptive use information in Chapter 4 can be used for reasonable estimates of the rate the crop is using moisture. If the rate of crop moisture use and the amount of soil moisture remaining are known, the date irrigation is needed can be predicted.

Soil moisture measurements should be made from the part of the soil from which plant roots extract their moisture and according to the moisture-extraction pattern of the particular crop. Regardless of the moisture measurement method used, the sampling procedures and selection of the moisture measuring stations are important.

Sampling Procedures

The sampling procedure should be as follows:

1. In uniformly textured soils, one measurement should be made at the midpoint in each quarter of the root zone. For shallow rooted crops it is probably desirable to take three measurements As an example, in a 24-inch zone, measurements may be taken from the 6-, 12-, and 18-inch depth.

2. In stratified soils, one measurement should be taken from each textural strata. It may not be necessary to take a measurement in very thin layers when this thin layer can be lumped with another layer from estimating soil moisture. Where the strata is thick a sample should be taken in 1-foot increments as a minimum. Thickness of the strata should be noted.

3. The crop root depth for annual crops changes through the early part of the growing season. Measurements should be made in the soil profile according to the current depth of the majority of the crop roots.

Selection of Moisture Measuring Station

The selection of soil moisture measurement stations is important. The stations should be located so that average soil moisture conditions in the root zone of the crop are measured. Excess water from leaks in pipe joints, low spots in a field, etc., should not be allowed to come in contact with the measurement station. High spots with excessive water runoff should not be chosen because the soil profile in this area will not represent average root zone conditions. Average soil and slope conditions in the field should be represented in station locations. Measurements should be made at other locations as indicated by any

critical condition in the soil, such as an area that dries out first. It is good practice to have at least two measurement stations in each critical area and two or three stations in areas that are typical of the field. This information provides direction for adjusting the amount and frequency of irrigation for different parts of the field or for different periods in the growing season.

1. Location in relation to plants.

   a. Row crops - locate in the crop row as near the plants as possible.

   b. Mature trees - located 8 to 10 feet from the trunk for pecans and 4 to 6 feet from the trunk for peaches and apples but inside the tree drip line; and

   c. Crops with complete cover such as alfalfa and grains - locate in representative soil and slope areas of the field.

2. Location in relation to irrigation systems.

   a. Lateral move sprinklers such as side roll or hand move aluminum pipe - locate measurement stations halfway between adjacent sprinkler heads and 10 to 15 feet from the lateral.

   b. Center pivot sprinklers - locate measurement stations at about two-thirds of the total lateral distance from the pivot.

   c. Traveling gun sprinklers - locate measurement stations midway between towpaths.

   d. Solid set sprinklers - locate measurement stations where the diagonals from four adjacent sprinkler heads cross.

   e. Trickle systems - locate in the wetted ball in the root zone.

3. Location in field for sprinkler or trickle irrigation systems. Sprinkler and trickle irrigation systems generally lose pressure down the lateral due to friction loss throughout the lateral so sprinkler heads farthest from the main lines put out the least irrigation water. To check adequacy of irrigations, locate measurement stations as follows:

   a. 50 to 100 feet downstream from the beginning of the lateral.

   b. 50 to 100 feet upstream from the distant end of the lateral.

MEASURING SOIL MOISTURE

Irrigation water management requires that soil moisture measurements be made to determine the amount of soil moisture available to the plants. Numerous techniques have been developed to obtain this information. A brief discussion of the more common methods follows. More detailed information can be found in Appendix A.

Feel and Appearance Method

With experience, and irrigator can achieve adequate accuracy by using the simple feel and appearance method to judge soil water content. Soil augers or probes are used to obtain soil samples down through the root zone of the crop. The percent of available moisture remaining is estimated by observing the feel and appearance while manipulating the sample according to a guide table (see Appendix A). The equipment required is simple and easily obtained, but requires time and effort to obtain reliable results. An added benefit of this method is that the irrigator actually observes his spoil profile and gains a better knowledge of the soil-plant-water relationship.

Gravimetric Method

The gravimetric method or oven dry method is the most accurate, but requires much time and effort to obtain the data. Soil samples are collected in the field and then oven dried in a lab. Moisture proof sample containers, a beam balance, drying oven (microwave can be used and reduce time needed to dry soil) and core samples are necessary equipment. This method gives the percent of total moisture in the soil, which must be converted to plant available moisture. It is used primarily for evaluation and research data and for calibrating other devices.

Tensiometers

Tensiometers measure soil moisture suction. They are a closed tube with a hollow ceramic tip at the soil contact end and a vacuum gage on the above ground end. It is filled with water and installed in the soil. As the soil dries, it pulls water through the ceramic tip, creating a vacuum inside the tensiometer. As the soil is wetted again from irrigation or rain, water is pulled back into the tensiometer, thus lowering the reading on the vacuum gage.

Most tensiometer gages read from 0 to 100 in centibars. One hundred centibars equal one bar, which is about the same as one atmosphere. A tensiometer can operate on the range of 0 to 80 centibars. A reading of 0 indicates a saturated soil. Different soil textures release water at different soil moisture tensions and, therefore, different tensiometer values. Readings of about 10 and 25 represent field capacity and ideal moisture aeration conditions respectively for sandy soils. Readings of about 30 to 60 represent corresponding conditions in clay soils.

Other soil texture combinations would utilize tensiometer values somewhere between these values for sand and clay soils. The wilting point occurs in the 1000 to 2000 centibar range which is well beyond the operating range of tensiometers.

Of the total water released by a soil between field capacity and the wilting point, the percentage released within the tensiometer measuring range may be as high as 90 percent for a sandy soil and as low as 30 percent for a clay soil. Tensiometers are best suited for soils that release 50 percent or more of their available water in the tensiometer range, 0 to 80 centibars.

Tensiometer readings tell when to irrigate, but do not tell how much to apply. Calibration curves are needed to relate soil tension to available moisture percentage (see Chapter 3, Irrigation and Crop Production Section, for general relationship and Appendix A).

Electrical Resistance Blocks

This method is based on the changes of electrical resistance of the blocks due to change in moisture contents. The blocks are buried in the soil, a change in the soil moisture makes a corresponding change in the moisture of the blocks. The electrodes in the blocks are connected by wires to the surface that can be connected to a portable resistance meter. Any change in the resistance of the blocks is an indirect measurement of the change of soil moisture tension. The reading can be calibrated in terms of percent moisture, but must be calibrated for specific soils. Resistance blocks are less sensitive than tensiometers in the range of 0 to 80 centibar range, but can operate in the range of field capacity to wilting point.

A special electrical resistance block is available that is as sensitive as a tensiometer, but will not have the high maintenance characteristics in the high tension region above 80 centibar.

SOIL MOISTURE COMPUTATIONS-DETERMINING WHEN AND HOW MUCH TO APPLY

General

Regardless of the mehtod used to measure soi moisture, it should either provide the answer on percent of plant available mositure remaining or have curves to convert to percent of available moisture. Appendix A shows the method used to convert the soil moisture measurement to percent of available moisture remaining for each of the soil moisture measurement methods discussed above.

Root Zone Water Balance

The minimum root zone moisture balance to be maintained is dependent upon the current rooting depth, AWC of the soil and the MAD (based on the crop's characteristics). For example, with an AWC of 2.2 in. for the rooting depth and a MAP of 40%, the minimum root zone balance to be maintained is 1.32 in. (2.2 in. x 0.60).

Computer programs are in use that estimate crop water usage from actual climatological data and maintain a current root zone water balance. They also predict crop water requirements, date of irrigation, and compute net irrigation requirements. The water balance computations are normally begun from initial soil moisture measurements. Subsequent measurements are also needed to verify predicted deficits. As discrepancies develop, the necessary corrections are made. These services may be available from commercial management firms that provide the irrigator weekly printouts containing scheduling information.

Farmers can also keep their own root zone water balance records. They will need to make soil moisture measurements to determine the initial soil moisture content and balance, as well as occasional measurements during the growing season to verify the computations. A rain gage will be needed to record the rainfall. Estimated crop water use the needs are provided by various means. It may be provided on a current basis through the local news media by a public agency or irrigation group using actual climatological data on a computer program. Seasonal data may also be available using normal climatological data from a local weather station. The consumptive use data in Chapter 4 of this guide can also be used.

Figure 11-1 illustrates one method that can be used to obtain estimated crop water use for scheduling irrigations. This method uses the consumptive use data contained in Chapter 4, Table 4-2, and is a plot of average daily consumptive use versus time. The curve is constructed by taking the monthly consumptive use and dividing by the number of days within the month (or part of month) and plotting this point at the midpoint of the month (or midpoint of the part month). This is done for each month of data. The point for the peak use period may be approximated by using the recommended design peak from table 4-1 of Chapter 4. When all the points are plotted a smooth curve is drawn connecting the points. In Figure 11-1 the monthly consumptive use curve was plotted for corn grown in climiatic zone 2. From Table 4-2, the consumptive use for May is 5.99 inches or 0.19 in./day (5.99 inches ÷ 31 days) average. This was plotted

AVERAGE DAILY CONSUMPTIVE USE CURVE FOR CORN CLIMATIC ZONE 2

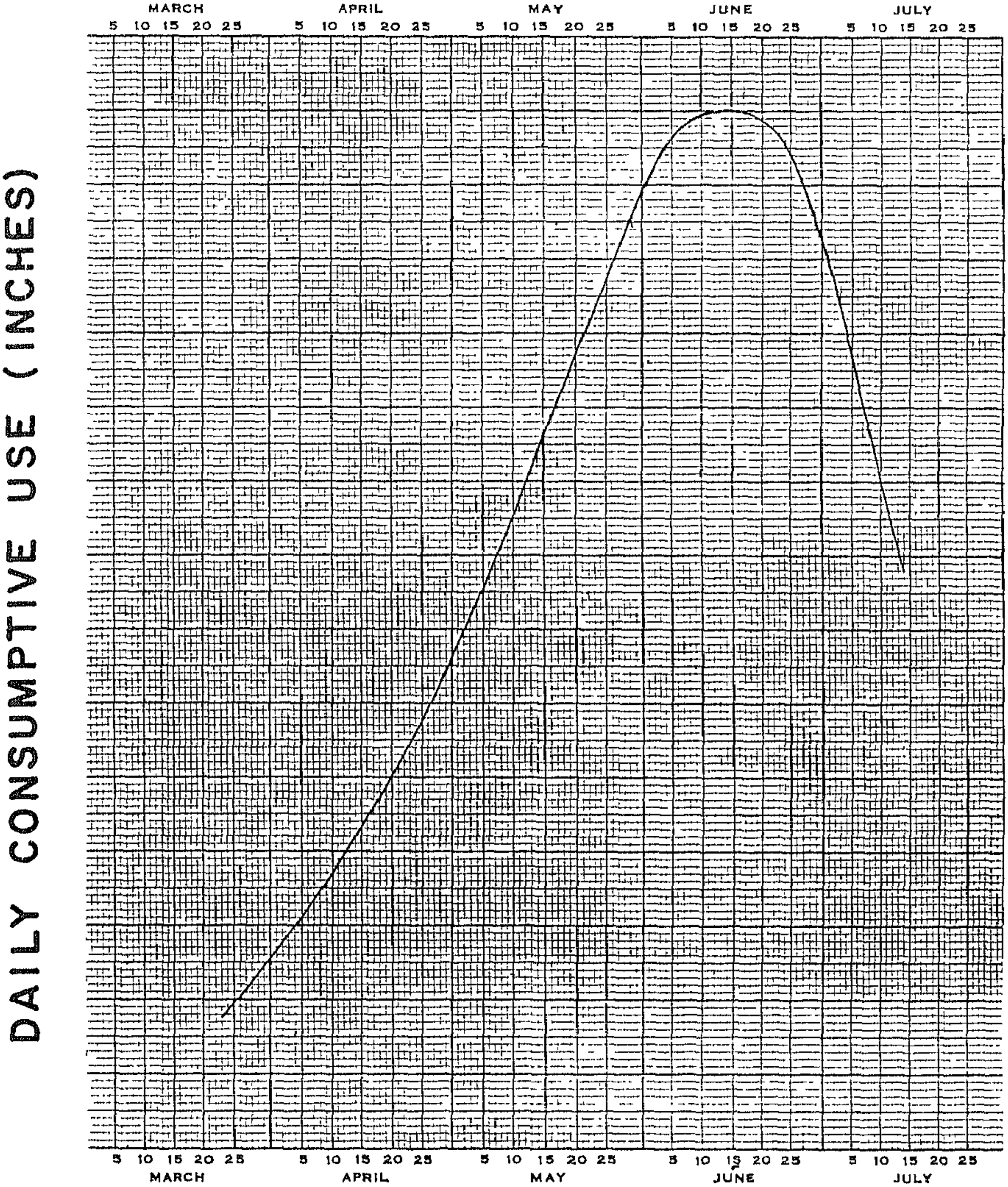


FIGURE II-1

on the graph at the middle of May. For June, the consumptive use is 6.98 inches or 0.23 in./day (6.98 inches ÷ 30 days) average. Since this is the peak use month, the peak value can be estimated by using the design peak from Chapter 4 of this Guide (0.3 in./day). This was plotted on the graph at the middle of June. Points were plotted for each month and the curve drawn connecting the points. The average daily consumptive use can be taken from the graph by projecting vertically from the day of the month in question until intersecting the curve and then projecting horizontally to read the consumptive use. For example, on May 5 the estimated consumptive use is 0.15 in./day.

Moisture Accounting Method of Scheduling

Once the consumptive use data and actual rainfall is obtained, the irrigator can schedule irrigations using the moisture accounting method. Figure 11-2 illustrates the accounting method for corn grown in climatic zone 2 for one month of the crop's growing season. Similar sheets would need be prepared for each month of the growing season. At the beginning of the season, moisture measurements should be taken and the moisture content determined. Moisture measurements should also be taken periodically during the growing season to verify soil moisture content or make adjustments as necessary. The example in Figure 11-2 shows that the AWC of the soil is 1.66 inches. With a MAD of 40%, irrigation is needed when the root zone moisture balance is 1.00 in. [(1.66 in. - (0.40)(1.66 in.)]. The example shows a balance from the previous month of 1.50 inches. Knowing the balance, it is a matter of subtracting the estimated consumptive use and adding any effective rainfall and/or irrigation. The account is kept on a daily basis. The estimated consumptive use in this example is taken from Figure 11-1. The rainfall can be measured using rain gages. It must be remembered that all rainfall is not effective. The rainfall may exceed the amount needed to fill the root zone to field capacity resulting in some of it lost to deep percolation or runoff. For example, referring to Figure 11-2, on May 8 a 1.5 inch rain occurred but the amount needed to refill the root zone was only 0.63 inches (1.66 in. - 1.03 in.). Therefore, .87 inches was not effective (1.50 in. - 0.63 in.).

Figure 11-2. Moisture Balance Sheet for
Scheduling Irrigation

Farm J. Doe Field No. 1 Crop Corn Month May Year 1986
County Orangeburg Climatic Zone 2 Soil Type Goldsboro
Moisture Holding Capacity in Root Zone 1.66 inches
Net Moisture to Apply at Each Irrigation ≈ 0.7 inches
Irrigate when balance is 1.0 inches

Date	Estimated Daily Consumptive Use, inches	Rainfall inches	Net Irrigation inches	Daily Balance Inches	Remarks
	Balance brought forward			1.50	Bal. brought froward from previous day
1	0.14			1.36	
2	.14			1.22	
	.14			1.08	
4	.15		0.73	1.66	Irrigate
	.15			1.51	
6	.15			1.36	
	.16			1.20	
8	.17	1.5		1.66	Rain replenished
	.17			1.49	
10	.17			1.32	
	.18			1.14	
12	.18		0.70	1.66	Irrig.
	.18			1.48	
14	.19			1.29	
	.19			1.10	
16	.20		0.76	1.66	Irrig.
	.20			1.46	
18	.20			1.26	
	.21			1.05	
20	.21		0.82	1.66	Irrig.
	.22			1.44	
22	.22			1.22	
	.23	0.8		1.66	
24	.23			1.43	
	.24			1.19	
26	.24		0.71	[illegible]	Irrig.
	.24	1.2			
28	.25			1.41	
	.25			1.16	
30	.25	1.0		1.66	
31	.26			1.40	
TOTALS	6.1		3.72		

Tensionmeter Method of Scheduling

Detailed information concerning use of tensionmeters for scheduling irrigatio is given in Appendix A. Tensionmeters are suited for use in medium and coars textured soils in the active root zone. Tensionmeters placed at shallow and deep depths as per Table A-2 (Appendix A) may be used to indicate when to begin and end irrigation respectively.

Pan Evaporation Method of Scheduling 1/

Evaporation from an open or screen-covered pan can be used to schedule irriga tion in either of two methods. The daily plan evaporation value can be used to estimate potential evapotranspiration (ET_p) in a water balance procedure. Based upon research results at Florence, South Carolina, evaporation from a screen-covered pan is approximately 0.87 open pan evaporation and can be usec to directly estimate ET_p. If open-pan evaporation is used, the values must b adjusted to estimate ET_p. The second method for using an evaporation pan to schedule irrigation is to modify the pan so that it can be used to physicall simulate ET_p on a daily basis. Due to the combined simplicity and reliabilit of this method, it has much potential for on-farm use and is described below.

Modifications include the installation of an overflow device to remove excess water and a rustproof (stainless steel, brass, etc.) measuring scale to measure water level in a standard National Weather Service Class A evaporatic pan. The overflow should be set so that the pan will fill to within 1-2 inches of the top edge of the pan before excess water is removed. The measuring scale should be mounted securely in the vertical position (e.g., to the side of the pan using a clamping device) so that it can be adjusted to place the scale reference point at the water surface when the pan is full (overflowing).

The amount of water that can be depleted from the soil profile before irriga- tion is initiated is dependent upon several factors, all determined by the specific site. Also, three assumptions required when using this method to schedule irrigation are that (1) pan evaporation is equal to RP_p, (2) all rainfall and irrigation infiltrates the soil, and (3) water from rainfall and irrigation in excess of soil storage is lost either as runoff of deep per- colation. Rooting depth, irrigation system efficiency, water storage capacit of the soil, and the fraction of water stored in the soil profile that can be depleted before irrigation is initiated (allowable depletion) must be known before the scale-setting calculation can be made. Details of the calculation of this value can best be explained through the use of an example.

Assume a center pivot system with an application efficiency of 80% is used to irrigate corn in an area which includes three soil types in the proportion indicated: Raines, 10%; Norfolk, 40%; and Wagram, 50%. Assume the moisture control zone for corn is estimated to be 24 inches, and irrigation is to be applied when 40% of the available water in the rooting zone is depleted. Available water capacity for the soil may be calculated using published SCS data for the individual soils. Assume the available water stored in the 24-inch rooting zone for the Norfolk, Wagram, and Raines soils is 2.3, 1.8, and 2.7 inches, respectively. This information can be used in several dif- ferent ways to estimate a representative value for available water stored

1/ By C. R. Camp and C. W. Doty with modifications by SCS.

in the soil profile under this center pivot system. Simple or weighted means of the three values are two obvious methods. A more conservative approach would be to use the value for the Wagram soil since it has the lowest storage value and comprises 50% of the area. One potential danger in this approach is that the other soils might become too wet if significant rainfall immediately follows irrigation, but the maximum difference in storage among these soils at the 50% level is only 0.45 inches, which is only a 1- or 2- day difference in irrigation timing. Available water stored in the soil profile may be calculated several times during the growing season, if desired, to reflect the changing rooting depth.

The amount of water to be applied at each irrigation is determined by the relationship, $I = (AW)(AD)/E$ where I is the amount of irrigation water to be applied, AW is the volume of available water in the rooting zone, AD is the allowable depletion (fraction of available water to be used by the crop before irrigation is applied), and E is the irrigation system efficiency expressed as a fraction. For this case, $I = (1.8)(0.5)/0.8 = 1.12$ inches.

The amount of pan evaporation required before irrigation is initiated is determined by the equation, $PE = (AW)(AD)/C$, where PE is pan evaporation required before irrigation is initiated, C is a crop coefficient relating ET to Ep, and other variables are as defined earlier. Recommended values of C are given below. For this example, using a C value of 1, $PE = 1.8(0.5)/1.0 = 0.9$ inches

Crop	Crop Stage	Crop Coefficient (C)
Corn	Emergence to 20 inch height	0.6[1/]
	20 inch height to maturity	1.0[1/]
Cotton	1st bloom to boll maturity	1.0
Soybeans	Emergence to canopy closure	-
	canopy closure to maturity	1.0[1/]
Peanuts	1st bloom to nut maturity	0.8
Snap beans	0 to 20 days from emergence	0.5[2/]
	21 to 30 days from emergence	0.6[2/]
	31 to 40 days fro	

example, if the scale was installed with zero at the original water surface), irrigation should be initiated. If the total amount of depleted water is not replaced by irrigation (partial or reduced irrigation), the depth of irrigation water actually applied (measured, if possible) is then added to the pan. If the total amount of depleted water is replaced by irrigation, water can be added to the pan until it overflows. For sprinkler irrigation systems, the pan may be placed under the irrigation system where it will receive the irrigation applied. if this is not possible, water must be added to the pan after each irrigation. When rainfall occurs, water level in the pan will rise proportionally, reflecting the increase in available water. Rainfall in excess of storage will be lost from the pan via the overflow. The evaporation pan simulator will operate in a similar manner for the entire season.

The pans used in research are stainless steel like those used by the National Weather Service and may cost several hundred dollars. Irrigators may make their own from a barrel or large galvanized tub. The pan, tube, or barrel should be about 2 feet or more in diameter and deep enough to hold at least a foot of water. This volume is needed to keep the water from heating up too much. Chicken wire should be secured over the top to keep wildlife out and will reduce evaporation by about 12 percent.

Household bleach may be added to the container to help keep water free of scum or algae.

1/ Doty, C.W., C.R. Camp, and G. D. Christenbury. 1982. Scheduling irrigation in the Southeast with a screened evaporation pan. Proc. Speciality Conf. on Environmentally South Water and Soil Management, Am. Soc. Civil Engr., Orlando, FL, July 20-23.

2/ Smittle and Stansel - Scheduling Snap Bean Irr. From Pan Evaporation Data, Tifton Ga., approx. 1981.

3/ Campbell, R. B. and C. J. Phene. 1976. Estimating potential evaporation from screened pan evaporation. Agric. Meteorol. 16:343-352

IRRIGATION WATER MANAGEMENT PLAN

GENERAL

An irrigation water management plan is an essential part of the conservation irrigation plan. See Chapter 7 for explanation and contents of an irrigation water management plan. Irrigation water management plans should be tailored to the individual site and the management expertise and desires of the irrigator.

CRITERIA

General requirements for an irrigation water management plan are contained in the SCS Technical Guide, Irrigation Water Management, Std. 449.

EXAMPLE IRRIGATION WATER MANAGEMENT PLAN

The following example is intended to cover the basic steps to follow in the development of an irrigation water management plan. An example irrigation water management plan is shown in Exhibit 11-1.

Given:

Develop an irrigation water management plan for the center pivot system in Chapter 10-C of this guide.

Solution:

Step 1. Provide the irrigator basic data such as: acres to be irrigated of each crop, water supply, irrigation flow rates, water quality, soil type, AWC, MAD, peak consumptive use rate, intake rate, irrigation efficiency, and rooting depth (water control zone). This data is contained in the irrigation data sheets as shown in Chapter 10-C. In this example, information would be provided to the irrigator by giving him a copy of the Irrigation Data Sheets 1-5.

Step 2. The various methods available to monitor or determine soil moisture should be discussed with the irrigator in such detail that he can select a method to use. Once he chooses a method, then work with him until he understands how to use the method. The irrigator in this example selected the feel and appearance method of determining soil moisture content along with tensiometers. The irrigator should be able to convert the soil moisture measurement to inches of water available to the crop. A form for converting soil moisture measurement to AWC was included in the irrigation water management plan Exhibit 11-1, sheet 1 of 6.

Appendix A shows how to convert the soil moisture measurement to AWC in inches for the major soil moisture measurement methods.

Step 3. Provide the irrigator with information on the crop water requirements - daily, monthly, and seasonal. These can be approximated by using computed values from Chapter 4 of this guide with the planting and harvest dates shown that are close to the actual dates. This example is for grain corn in climatic zone 2. This data would be given to the irrigator and is shown on Exhibit 11-1, sheet 2 of 6. The irrigator should have an understanding that this information is estimated. Also he should have an understanding of effective rainfall (i.e., that all rainfall is not available for the crop).

Step 4. The irrigator should have a method to determine when to irrigate (i.e., an irrigation scheduling procedure). The different methods should be explained to the irrigator in such detail that he can select a method. Once the irrigator has selected a method to use in scheduling irrigations, he should be taught how to use it. In this example, the irrigator selected to use the tensionmeter method. Needed information would be prepared for the irrigator and included in the irrigation water management plan, Exhibit 11-1, sheet 3 of 6.

Step 5. The critical stages of growth where sufficient moisture is necessary for crop production should be provided to the irrigator. The information can be obtained from Chapter 3, Table 3-2, of this guide. The critical periods for corn were included in the irrigation water management plan, Exhibit 11-1, sheet 4 of 6.

Step 6. The irrigator should know how much to apply. The net amount to apply for this example was determined by the feel and appearance method of estimating the AWC and MAD and will vary at different rooting depths (i.e., crop growth stages). The gross amount to apply is the net amount divided by the irrigation system efficiency. The irrigator should understand that the irrigation system is not 100% efficient in delivering water to the field and that he should divide the net amount by the irrigation efficiency to obtain the gross amount to apply. Irrigation efficiency was given on the irrigation data sheets as 70 percent.

The irrigator should know the application rate of his irrigation system (in./hr) in order to determine the time needed to apply the required water. In the case of self-propelled irrigation equipment, operating adjustments should be made to apply the necessary irrigation amount. For center pivot systems a table should be developed to relate the dial setting to the gross water applied. Chapter 10-C of this guide gives a procedure for determining gross application of center pivot systems. The dial setting for this system was computed and included in the irrigation water management plan, Exhibit 11-1, sheet 4 of 6, showing the gross amount and net amount applied.

Step 7. The irrigator should be taught how to recognize erosion caused by irrigation and excess runoff of irrigation water and should be provided ways to make adjustments to prevent runoff. The information provided will vary with each situation due to the variance in erosion potential of soils, land slope, soil intake rate, etc. A statement was made for this example and included in the irrigation water management plan, Exhibit 11-1, sheet 4 of 6.

Step 8. The irrigator should be provided a method of evaluating the performance of his irrigation applications. This would consist of explaining the reasons to evaluate the system and forms that would be helpful in evaluating the system. It may be necessary to work with the landowner on the first evaluation to teach him how to gather and interpret the data. In this example, forms were included in the irrigation water management plan, Exhibit 11-1, sheets 5 of 6 and 6 of 6. Plans were made to assist the irrigator in evaluating his irrigation system. Appendix B gives information on how to evaluate irrigation systems.

Exhibit 11-1

IRRIGATION WATER MANAGEMENT PLAN

Cooperator: Bill Jones Field No. 3 Sheet 1 of 6

Location: Orangeburg Co.

1. Format for figuring the net amount of water needed for an irrigation using the feel and appearance method of soil moisture measurements.

(1) Depth (feet)	(2) Soil Series Fuquay (texture)	(3) Available water capacity (inches)	(4) Soil water content before irrigation (percent)	(5) (inches)	(6) Soil water deficiency (inches)
0-1.5	Loamy Sand	0.90	50	0.45	0.45
0-2.0	" "	1.20	50	0.60	0.60

Column 1, the depth increment sampled.
Column 2, the soil texture of the sample.
Column 3, the available water capacity based on the texture of the sample.
AWC (inches) = depth (inches) x AWC (in./in.)
Column 4, the percent of soil water content (remaining).
- 0-25% AWC - Dry, loose, flows through fingers.
- 25-50% AWC - Looks dry, will not form ball with pressure.
- 50-75% AWC - Will form loose ball under pressure, will not hold together even with easy handling.
- 75-100%AWC - Forms weak ball, breaks easily, will not "slick."

Column 5, Column 3 x Column 4, the soil-moisture balance, inches.
Column 6, Column 3 - Column 5, soil-moisture deficiency or net irrigation requirement.

2. Alternate format for figuring the net amount of water needed for an irrigation using soil water tension versus water content (average values obtained from table 2-1 for coastal plain soils).

Estimated soil moisture content @ 0.10 bar tensiometer reading = .13 in./in.

Estimated soil moisture content @ 0.30 bar tensiometer reading = .10 in./in.

For early to mid-season corn, net amt. to irrigate = 18" depth x .03 = 0.54"

For mid to late season corn, net amt. to irrigate = 24" depth x .03 = 0.72"

Crop - Corn, Grain

Moisture Allowed Deficiency (MAD) = 50%

Approx. Planting Date - March 20

Approx. Maturity Date - July 8

Month	Estimated Consumptive Use - inches	Estimated Accumulated Consumptive Use - inches
March	0.4	0.4
April	2.6	3.0
May	6.0	9.0
June	7.0	16.0
July	1.8	17.8

Exhibit 11-1

IRRIGATION SCHEDULING INFORMATION

Crop - Corn Soil - Fuquay Loamy Sand

Method - Tensiometers

Number of Tensiometers - 2 each at three locations as shown on Plan Map (place in the crop rows).

Tensiometers should be placed as follows:

Time of Season	Estimated Depth of Water Control Zone	Recommended depths of setting Tensiometers Shallow	Deep	Estimated net water to apply Initially1/
Early to mid-season (corn generally less than 3' high)	18"	8"	12"	0.45
Mid-to late season	24"	12"	18"	0.6

Begin irrigation when shallow tensiometer reads 30 centibars (.3 bars). After the initial application, vary the application amount as needed so that the deep tensionmeter reading drops to about 10 centibars (.10 bars) within 1 to 12 hours afterwards.

1/ Value given for net watér to apply is for estimating purposes only based upon the feel and appearance method of estimating soil moisture as given on p. 1 of 6. Install tensiometers and service at regular intervals as recommended by mfg.

Exhibit 11-1
IRRIGATION WATER MANAGEMENT PLAN

CRITICAL GROWTH STAGE

Demand for water is especially high and important during the tasseling and grain filling period. The grain filling period is the 3 weeks following tasseling.

Corn should never be allowed to wilt appreciably. If limited irrigation is necessary, the critical period for irrigation is from the tassel stage through grain filling.

IRRIGATION APPLICATION

Irrigation to be Applied, Inches		Time Required per Revolution-Hours	Dail Setting
Net	Gross (@ 70% efficiency)		
.21	0.30	15.4	100
.24	.34	17.1	90
.27	.38	19.2	80
.31	.44	22.0	70
.36	.51	25.7	60
.43	.61	30.8	50
.53	.76	38.5	40
.71	1.02	51.3	30
1.06	1.52	77.0	20
2.14	3.05	154.0	10

EROSION OR EXCESS IRRIGATION RUNOFF

Soil intake rate can change. The intake rate will usually decrease the longer the irrigation time (i.e., during the lower dial settings). Visual observations should be made to determine if erosion or excess runoff occur Appropriate adjustments in the irrigation system operation or other conservation practices should be applied to reduce erosion and runoff as needed

Exhibit 11-1
IRRIGATION WATER MANAGEMENT PLAN

CENTER PIVOT SPRINKLE IRRIGATION EVALUATION

1. Location______________, Observer_____, Date & Time__________________

2. Equipment: make________, length_____ft, pipe diameter___________in

3. Drive: type________speed setting_____%, water distributed? ________

4. Irrigated area = $\dfrac{3.14 \text{ (wetted radius \_\_\_\_\_\_ ft)}^2}{43{,}560}$ = __________acres

5. N wind

*Mark position of lateral direction of travel, elevation differences, wet or dry spots and wind direction.
Wind______mph, Temperature_____°F

Pressure: at pivot____________psi
at nozzle end________psi
Diameter of largest nozzle______in

Comments: ______________________

____

6. Crop: condition______________________________, root depth__________ft

7. Soil: texture ________, tilth ______, avail. moisture _________in./ft.

8. SMD: near pivot ________ in, at 3/4 point _______in, at end ______in.

9. Surface runoff conditions at 3/4 point _____, and at end______________

10. Speed of outer drive unit ____ft per _____min = ________________ft/min

11. Time per revolution = $\dfrac{\text{(outer drive unit radius \_\_\_\_ ft)}}{\text{9.55 (speed \_\_\_\_\_\_ ft/min}}$ = __________hr

12. Outer end: water pattern width _______ft, watering time _________min

13. Discharge from end drive motor _________gal per ______min= ________gpm

14. System flow meter ________________gallons per _________min = ______gpm

15. Average weighted catches:

System = $\dfrac{\text{(sum all weighted catches \_\_\_\_\_\_\_\_)}}{\text{(sum all used position numbers \_\_\_\_\_\_\_)}}$ = _________ml = ____in

Low 1/4 = $\dfrac{\text{(sum low 1/4 weighted catches \_\_\_\_\_\_\_\_)}}{\text{(sum low 1/4 position numbers \_\_\_\_\_\_\_\_\_\_)}}$ = _______ml = ___in

16. Minimum daily (average daily weighted low 1/4) catch:

$\dfrac{\text{(\_\_\_ hrs operation/day) X (low 1/4 catch \_\_\_\_\_\_ in)}}{\text{(\_\_\_\_\_\_\_\_\_ hrs/revolution)}}$ = __________in/day

Exhibit 11-1

IRRIGATION WATER MANAGEMENT PLAN

CENTER PIVOT SPRINKLE IRRIGATION EVALUATION (Cont.)

17. Container catch data in units of ______, Volume/depth ______ ml/in

Span length ______ ft, Container spacing ______ ft

Evaporation: initial ______ ml ______ ml

final ______ ml ______ ml

loss ______ ml ______ ml, ave ______ ml = ______ in

Span no.	Container Position Number	X Catch =	Weighted Catch	Span No.	Container Position Number	X Catch =	Weighted Catch
	1				37		
	2				38		
	3				39		
	4				40		
	5				41		
	6				42		
	7				43		
	8				44		
	9				45		
	10				46		
	11				47		
	12				48		
	13				49		
	14				50		
	15				51		
	16				52		
	17				53		
	18				54		
	19				55		
	20				56		
	21				57		
	22				58		
	23				59		
	24				60		
	25				61		
	26				62		
	27				63		
	28				64		
	29				65		
	30				66		
	31				67		
	32				68		
	33				69		
	34				70		
	35				71		
	36				72		

Sum all: used position numbers ______, weighted catches ______

Sum low 1/4: position numbers ______, weighted catches ______

SOUTH CAROLINA IRRIGATION GUIDE

CHAPTER 12. IRRIGATION WATER MEASUREMENT

Contents

Figures

CHAPTER 12. IRRIGATION WATER MEASUREMENT

GENERAL

Reasonably accurate water measurement is necessary for proper design and evaluation of an irrigation system. The units of flow measurement commonly used for water are cubic feet per second (cfs) and gallons per minute (gpm).

The following equivalents may be found useful:

1 gallon (gal) = 231.02 cubic inches = 0.1337 cubic feet

1 gallon of water weighs 8.33 pounds

1 million gallons = 3.0689 acre-feet

1 cubic foot (cu ft) = 1,728 cubic inches
= 7.48 gallons

1 cubic foot of water weighs 62.4 pounds

1 acre-foot (ac-ft) = amount required to cover one acre one foot deep
= 43,560 cubic feet
= 325,828.8 gallons
= 12 acre inches

1 gallon per minute (gpm) = 0.00223 cubic feet per second
= 1,440 gallons per day (24 hrs)

1 million gallons per day (mgd) = 1.547 cfs
= 694.44 gpm

1 cubic foot per second (cfs) = 7.48 gallons per second
= 448.8 gpm
= 646,272 gpd
= 0.992 acre
= 1,983 acre

It is common practice in planning to round off certain conversion factors such as:

1 cfs = 450 gpm
= 1.0 acre-inch per hour
= 2.0 acre-feet per day

Many methods of water measurement have been used in different situations for different purposes. The methods herein discussed will be as follows:

(1) methods of measuring small irrigation streams, (2) methods of measuring pipe flow, and (3) methods of measuring channel flow.

METHODS OF MEASURING SMALL IRRIGATION STREAMS

VOLUMETRIC

Volumetric flow measurements are made by measuring the time required to fill a container of known volume.

$$Q \text{ (gpm)} = \frac{\text{Volume of water (gal)} \times 60}{\text{Time required to fill container (seconds}}$$

Refer to NEH 15, pages 9-3 to 9-5.

SUBMERGED ORIFICE PLATES

The submerged orifice plate is placed across the furrow and the head through the orifice is measured under submerged conditions. See Figu 12-1.

Orifice plates consist of small sheet iron, steel, or aluminum plates that contain accurately machined circular openings or orifices usual ranging from 1 to 3½ inches in diameter.

In use, an orifice size is selected so as to produce a head differen within the 0.50 to 2.5 inch range, and the plate is placed in and ac the furrow with its top as nearly as level as possible. Flow throu the orifice must be submerged.

Flow through the orifice is calculated by the standard orifice form

$Q = CA \quad 2gH$, (cfs) which for gallons per minute can be wr

$Q = 7.22 \, Ca \quad h$

Where Q = gpm

C = coefficient of discharge (use 0.60 for approximate

h = head differential in inches

a = area in square inches

See NEH 15, pages 9-5 to 9-7 for more information.

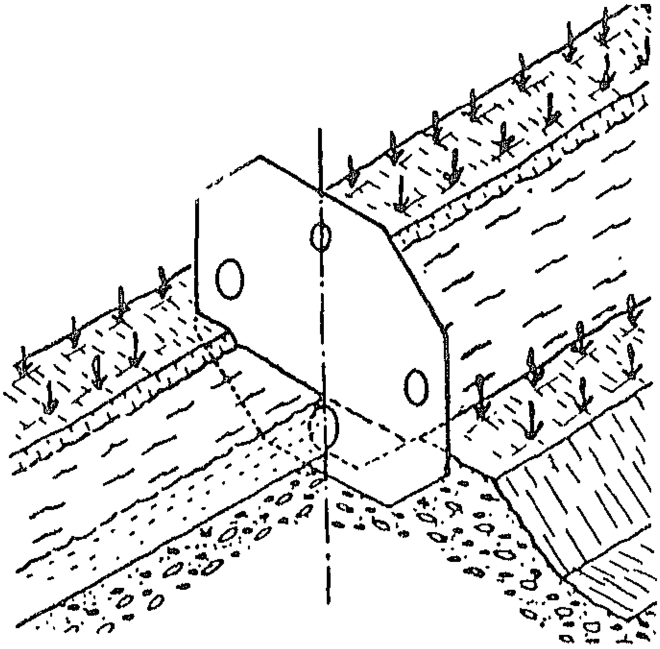


Figure 12-1. Submerged Orifice Plate

WASHINGTON STATE COLLEGE (WSC) FLUME

The WSC measuring flume, developed at the Washington State College, adapts the Venturi principle to the measurement of flow in small channels. This flume consists of four principle sections: An entrance section upstream, a converging or contracting section leading to a constricted section or throat, and a diverging of expanding section downstream (Figure 12-2). The bottom of the flume is placed level, both longitudinally and transversely, at a height equal to or slightly higher than the channel bottom. Only one reading on the slanting scale is required. This reading is readily converted to gallons per minute by the use of tables. See NEH Section 15, Chapter 9, pages 9-10 - 9-12 for more information.

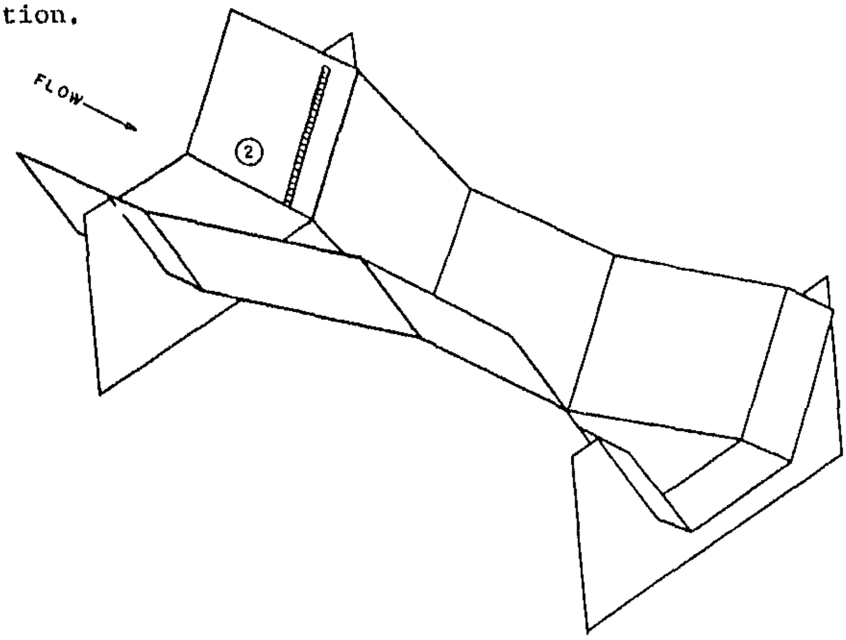


Figure 12-2. WSC Flume

SIPHON TUBES

Siphon tubes, used to remove water from a head ditch and distribute it over a field through furrows, corrugations, or borders, are also used to measure the rate of flow into these distribution systems.

These tubes, made of aluminum, plastic, or rubber, are usually preformed to fit a half cross section of the head ditch. The normal diameter range is from 1 to 6 inches, although both smaller and larger sizes are available. The smaller sizes are used with furrows and corrugations and the larger sizes with borders. Various lengths are available.

See NEH 15, Chapter 9, pages 9-10 to 9-14 for more information.

METHODS OF MEASURING PIPE FLOW

PIPE ORIFICES

Pipe orifices are usually circular orifice plates placed within or at the end of a circular pipe (see Figure 12-3). The head on the orifice is measured with a manometer. A manometer is a device that measures the pressure differential in feet of water or inches of mercury. The orifice is often used for well discharge measurement from wells in a range of 50 to 2000 gpm. Discharge through the orifice is computed by the formula:

$$Q = CA \quad 2\,gh$$

where Q = Discharge in gpm

C = Coefficient of discharge (See Fig. 9-8, Section 15, Chapter 9, NEH)

a = cross sectional area of the orifice in square inches

g = Acceleration due to gravity = 32.2 ft/sec^2

h = head on the orifice in inches measured above the center for free flow.

For discharge tables refer to NEH 15, Chapter 9, Table 9-5.

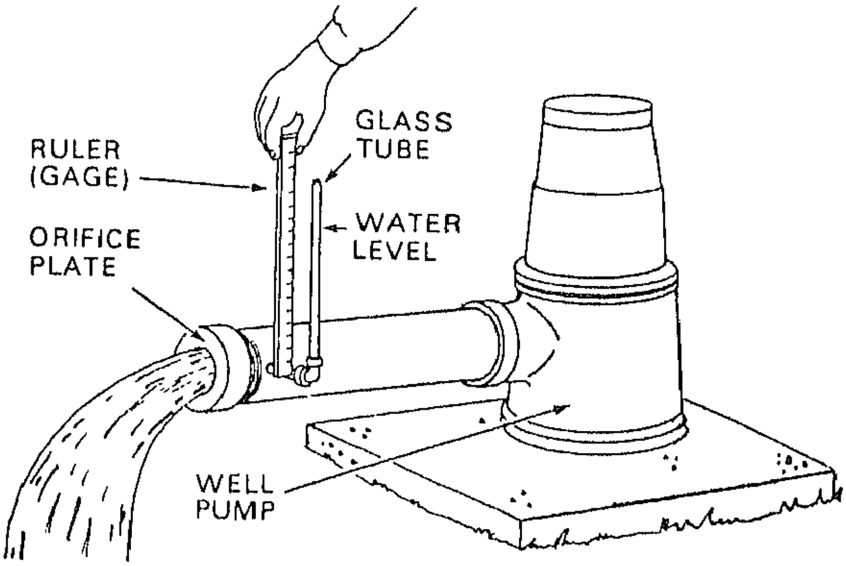


Figure 12-3. Pipe Orifice

VENTURI METERS

The Venturi meter measures the flow in a pipe under pressure. It utilizes the Venturi principle in that flow passing through a constricted section of pipe is accelerated and its pressure head lowered. With the relative cross sectional areas known the flow is measured by measuring the drop in pressure. For further information, refer to pages 9-17 to 9-20, Section 15, Chapter 9, NEH (see Figure 12-4).

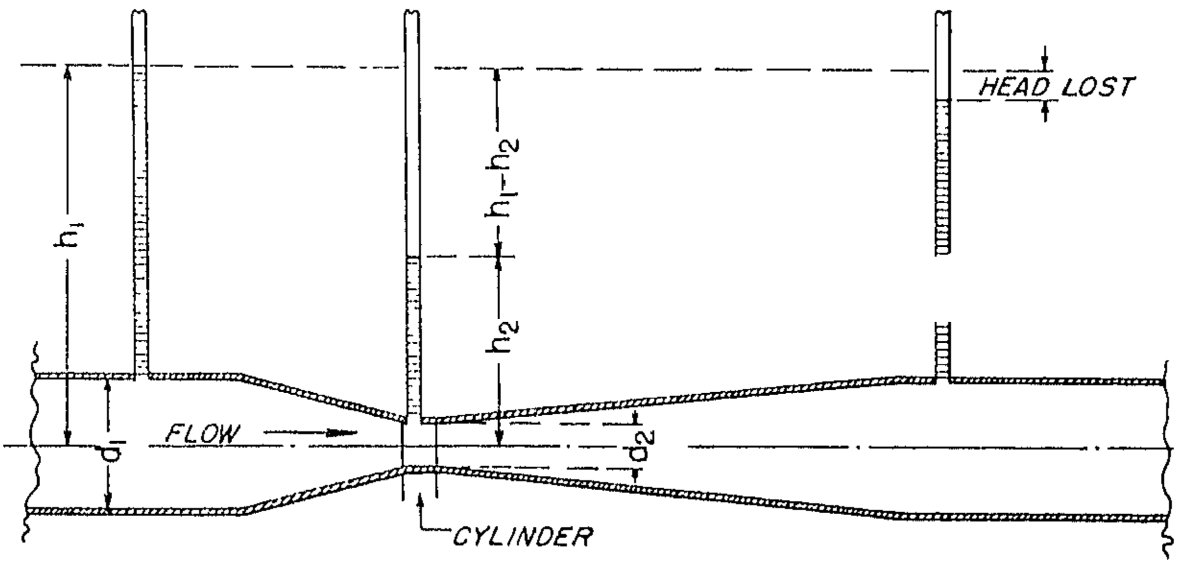


Figure 12-4. Venturi Meter

IRRIGATION FLOW METER

Meters of this type are generally of the velocity type. They essentially consist of a conical propeller connected to a registering head by a gear train (see Figure 12-5). They are operated by the kinetic energy of the flowing water. Three basic types are mainly used: (1) low-pressure line meters, (2) open-flow meters, and (3) vertical-flow or hydrant-type meters. Flow tables and charts are available from each company making the device.

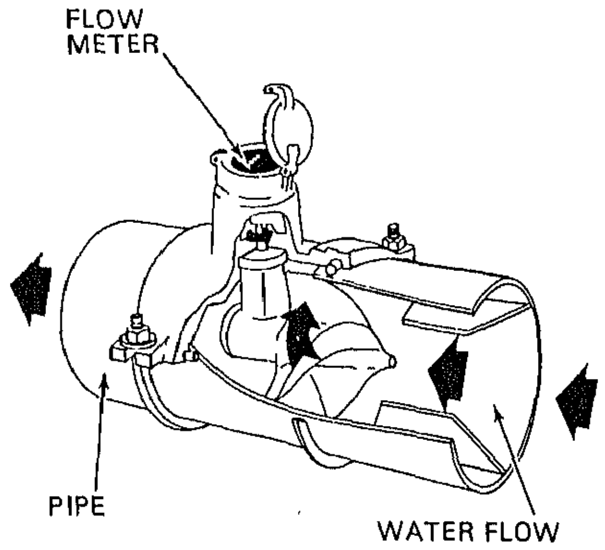


Figure 12-5. Irrigation Flow Meter

COORDINATE METHOD

In a coordinate method, coordinates of the jet issuing from the end of a pipe are measured (see Figure 12-6). The flow from the pipe can be measured whether the pipe is discharging horizontally or vertically. They should be used only where facilities for more accurate measurement are not available, and where an error of up to 10% is permissible. Refer to pages 9-24 through 9-28 of Section 15, Chapter 9, of the NEH of procedures and tables.

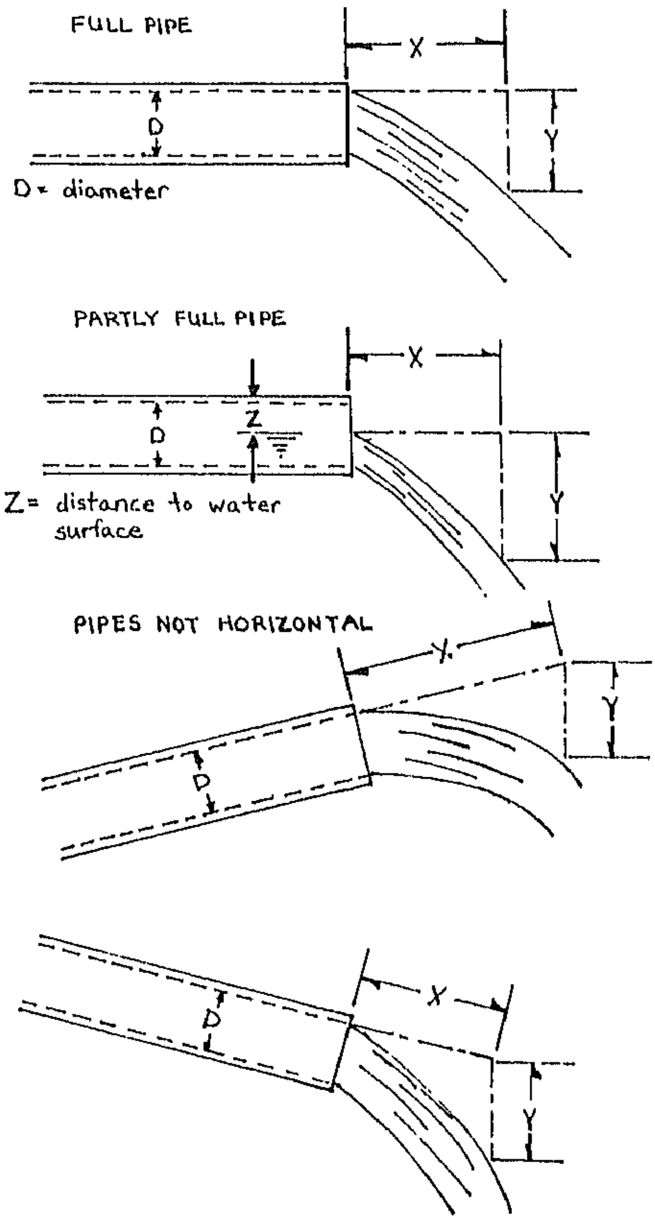


Figure 12-6. Coordinate Method

METHODS OF MEASURING CHANNEL FLOW

FLOAT METHOD

The flow rate can be estimated by timing the passage of a small float through a measured length of channel. The procedure for estimating rate of flow by the float method is as follows:

1. Select a straight section of ditch with fairly uniform cross sections. The length of the section will depend on the current, but one hundred feet usually will be adequate. A shorter length may be satisfactory for slow flowing ditches.

2. Make several measurements of depth and width within the trial section, to arrive at the average cross section area. The area should be expressed in terms of square feet (see Figure 12-7).

3. Place a small float in the ditch a known distance upstream from the upper end of the trial section. Determine the number of seconds it takes for the float to travel from the upper end of the trial section to the lower end. Make several trials to get the average time and travel. The best floats are small rounded objects which float nearly submerged. They are less apt to be affected by wind or to be slowed by striking the side of the channel. Among small objects which make good floats are a long necked bottle partly filled with water and capped, a rounded block of wood, or an orange. A wooden sphere, like a croquet ball, is excellent.

4. Determine the velocity (or speed) of the float in units of feet per second by dividing the length of the section (in feet) by the time (in seconds) required for the float to travel that distance.

5. Determine the average velocity of the stream. Since the velocity of the float on the surface of the water will be greater than the average velocity of the stream, the float velocity must be multiplied by a correction coefficient to obtain a good estimate of the true average stream velocity. The correction factor varies with the type of float used with the shape and uniformity of the channel. With floats that sink only an inch or two below the water surface, a coefficient of about 0.80 should be used for most unlined farm ditches. A coefficient of 0.85 is appropriate for smooth uniform lined ditches. With floats that extend two-thirds or more of their depth below the surface, the coefficients should be about 0.85 for unlined ditches and 0.90 for lined ditches (see Figure 12-8).

Station 0+00

Distance from left water edge	(ft.)	0.0	1.5	3.6	5.0
Water depth	(ft.)	0.00	1.10	1.15	0.00

$$\text{Area} = \frac{1.10 \times 1.5}{2} + \frac{(1.10 + 1.15)}{2} 2.1 + \frac{1.15 \times 1.4}{2}$$

$$= 0.82 + 2.36 + 0.81 \qquad = 3.99$$

Station 0+40

Distance from left water edge	(ft.)	0.0	1.3	3.8	5.2
Water depth	(ft.)	0.00	0.85	1.05	0.00

$$\text{Area} = \frac{0.85 \times 1.3}{2} + \frac{(0.85+1.05)2.5}{2} + \frac{1.05 \times 1.4}{2}$$

$$= 0.55 + 2.37 + 0.73 \qquad = 3.65$$

Station 0+90

Distance from left water edge	(ft.)	0.0	0.9	1.9	3.3	4.8
Water depth	(ft.)	0.00	0.80	1.15	1.15	0.00

$$\text{Area} = \frac{0.80 \times 0.9}{2} + \frac{(0.80+1.15)}{2} + \underline{1.15 \times 1.4} + \frac{1.15 \times 1.5}{2}$$

6. Compute the rate of flow. The rate of flow is obtained by multiplying the average cross sectional area (Item 2) by the average stream velocity (Item 5) (see Figure 12-8). The accuracy of these estimates of flow rates is dependent upon the precisenes with which average cross sectional areas and float velocities hav been determined and upon the selection of the proper correction coefficient.

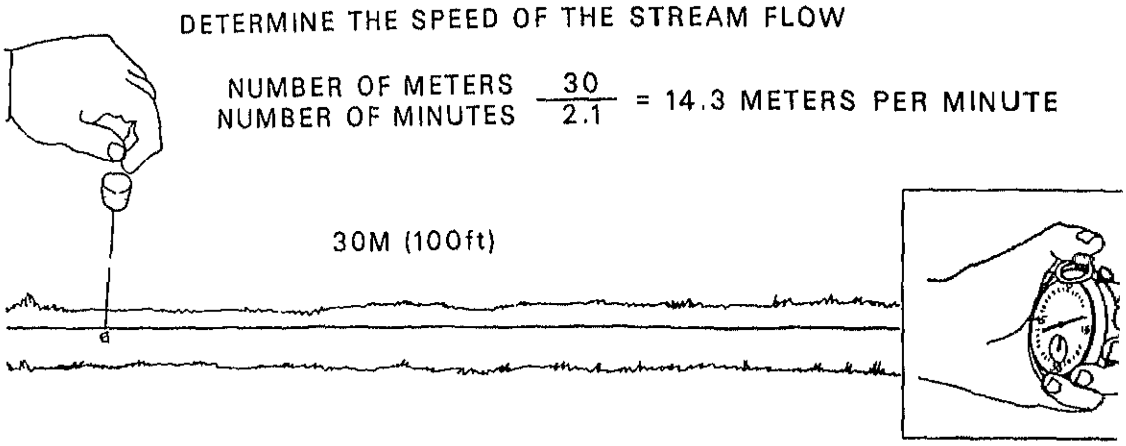


Figure 12-8. Computing Channel Flow

SUBMERGED ORIFICE

A submerged orifice is a hole in a bulkhead through which water flows under submerged conditions. The opening of a standard submerged orif is sharp edged and usually rectangular with a width 2 to 6 times the height. They can be used in channels having grades which may be too flat for weir operation. The forumla used is the same as for pipe orifice:

$$0 = ca \sqrt{2\ gh}$$

0.61 for orifices with complete contraction.

Refer to pages 9-63 to 9-65, Section 15, Chapter 9, NEH for installat procedures and flow tables.

GATES

Gates can be arranged and calibrated to operate as a type of submerged orifice. The same pipe orifice formula applies:

$$Q = ca\sqrt{2gh}$$

The c value here will be a variable depending on the nature of the specific gate opening. When the discharge is free, the head (h) is the difference in elevation between the upstream water surface and the center of the gate. Figure 9-33, Section 15, Chapter 9, NEH gives an illustration and flow chart for a commercial meter gate.

WEIRS

A weir notch is one of the simpler water measuring devices to use and construct (see Figure 12-9). There are three general types depending on the shap of the notch: (1) rectangular, (2) trapezoidal of Chipolletti, and (3) 90° triangular. They require considerable loss of head, often not available in ditches on flat grades. Triangular weirs give the most accurate readings on flows of less than 1 cfs. Rectangular and trapezoidal flumes are used to measure discharges up to 75 cfs or more. Refer to NEH, Section 15, Chapter 9.

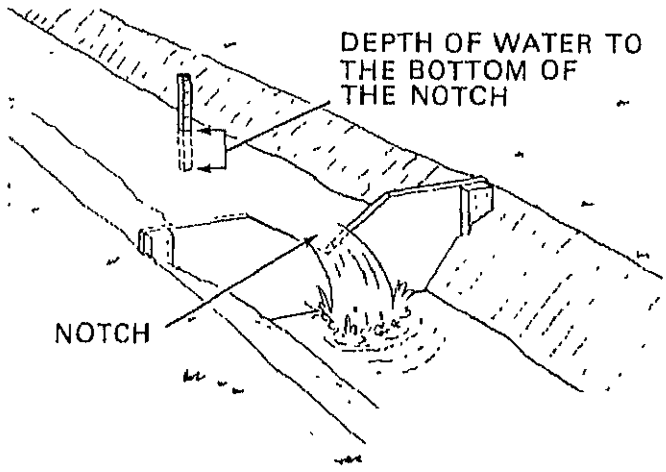


Figure 12-9.

FLUMES

There are three major types of flumes used to measure irrigation water: (1) Parshall (see Figure 12-10), (2) trapezoidal, and (3) cutthroat. They all operate similarly and require less operating head than weirs. They all have a converging or contracting section, a constricted section or throat, and a diverging or expanding section. The ARS cast-in-place, 2-foot concrete trapezoidal flume was designed for use in trapezoidal irrigation canals flowing up to 50 cfs.

The cutthroat flume was developed as a portable flume, although it can be permanently installed, for flows up to 10 cfs. The Parshall is generally a permanently installed flume and used to measure flows up to 100 cfs or more. Refer to NEH, Section 15, Chapter 9, for Parshall flume. Refer to USDA-ARS Technical Bulletin No. 1566 for the cast-in-place trapezoidal flume and for the cutthroat flume.

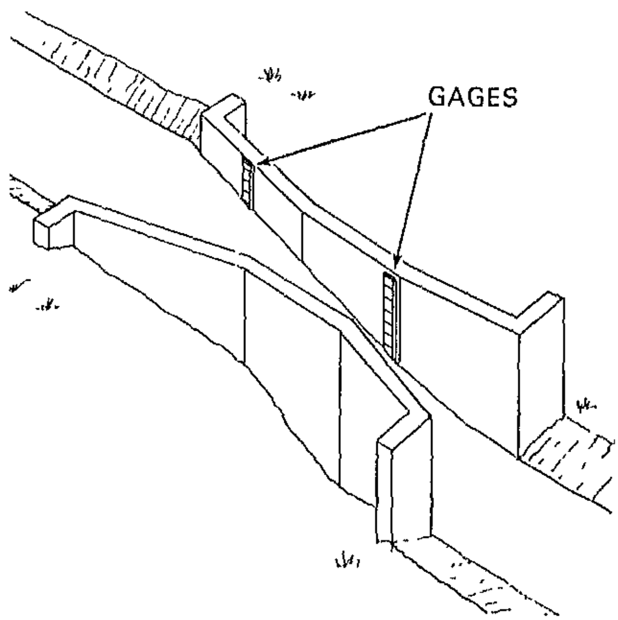


Figure 12-10. Parshall Flume

CURRENT METERS

The current meter is similar to the flow meter in that it measures the velocity of flow by means of propeller. The RPM of the propeller is usually measured by counting the breaks in an electric circuit while listening through headphones, and using a stop watch. They are either suspended from cables over a channel or mounted by rods and carried by hand through the channel. Current meters are rated by the manufacturer, and a rating table is furnished. Measurements are usually taken every 2 to 10 feet across the channel depending on the width of the channel. Readings are commonly taken at 0.2 and 0.8 of the depth measured from the water surface. The average of these two values is the average velocity in depth. For further details refer to pages 9-28 through 9-30, Section 15, Chapter 9, of the NEH.

Culvert Method

If a culvert is near the area where a flow measurement is needed, the velocity can be determined by the float method discussed on page 12-8 using the appropriate coefficients for lined ditches.

The flow is determined by use of the following chart:

HYDRAULIC PROPERTIES OF CULVERTS FLOWING PARTIALLY FULL

	d' (Depth factor)	a' (Area of Flow Factor)		d' (Depth factor)	a' (Area of Flow Factor)
Full	1.0	0.7854	Half	0.5	0.3927
	0.95	0.7708		0.4	0.2934
	0.9	0.7445		0.3	0.1981
	0.8	0.6735		0.25	0.1536
	0.7	0.5874		0.2	0.1118
	0.6	0.4920		0.1	0.0408
			Empty	0.0	0.0

Adapted From Handbook of Culvert and Drainage Practice 1947

Depth factor (d') is expressed as depth of flow in culvert divided by culvert diameter (D). $d' \text{ (in table)} = \dfrac{\text{Depth of flow}}{\text{Diameter (D)}}$

Measure depth of flow at both ends and use average depth in calculations.

Multiplying area of flow factor (a') by the pipe diameter squared $(D)^2$ for the corresponding depth of flow.

Multiply this area by the velocity in feet per second to obtain flow in CFS.

Example Problem - Determine culvert flow.

Given: Average velocity in a 2.0 foot diameter culvert is estimated to be 2.0 ft/sec.
Average measured depth of flow in the culvert = 1.5 ft.

Solution: $d' = \dfrac{\text{Depth of flow}}{D} = \dfrac{1.5}{2} = 0.75$

Interpolating from chart: $a' = \dfrac{.6735 + .5874}{2} = 0.63$

Area of flow $= a'D^2 = 0.63(2)^2 = 2.52$ sq. ft.

Culvert Flow $= 2.52(V) = 2.52(2) = \underline{\underline{5.0 \text{ cfs}}}$

Appendix A - Measuring Soil Water Content

Contents

Figures

Tables

Guide for Judging how much Moisture is Available for Crops

	Feel or Appearance of Soil			
	Loamy Sand or Sand	Sandy Loam	Loam and Silt Loam	Clay Loam or Silty Clay Low
	Dry, loose, single grained, flows through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometime slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked, sometimes has loose crumbs on surface.
25 percent	Appears to be dry, will not form a ball with pressure. 1/	Appears to be dry, will not form a ball. 1/	Somewhat crumbly but holds together from pressure.	Somewhat pliable, will ball under pressure. 1/
50 percent	Appears to be dry, will not form a ball with pressure.	Tends to ball under pressure but seldom holds together.	Forms a ball somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball, ribbons out between thumb and forefinger.
75 percent	Tends to stick together slightly, sometimes forms a very weak ball under pressure.	Forms weak ball, breaks easily, will not slick.	Forms a ball, is very pliable, slicks readily is relatively high in clay.	Easily ribbons out between fingers, has slick feeling.
At field capacity (100 percent)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.

1/ Ball is formed by squeezing a handful of soil very firmly.

d. Tensiometers are set in stations. A "station" consists of two or more tensiometers at different depths placed near one another.

e. Two stations may be enough in a field with uniform soil and slope. One station should be near the upper end of the field and the other near the lower end. More tensiometers may be needed in areas where the soils or slopes vary from representative soils or slopes in the field. When placing tensiometers, the following suggestions should be kept in mind

(1) In row crops, the tensiometers should be placed in the crop row. Stations should be at points where the plant population is representative of the field.

(2) For orchards, the tensiometers should be located within the drip line and 3 to 6 feet from the tree trunk and on the sunny side.

(3) Measuring stations should be in representative soil areas of the field. Tensiometers should not be placed in low spots in the field.

(4) Tensiometers should be placed after the last freeze in the spring and should be removed before the first freeze in the fall.

f. Depth of tensiometer installation is determined by the active root zone of the crop. This active root zone depends upon the crop, stage of growth, and depth of soil. Recommended depths for setting tensiometers are given in Table A-2. Tensiometers should not be installed in a fine textured soil at the shallow root depth because soil suction will exceed 100 centibars before the management allowed deficiency is reached.

Table A-2. RECOMMENDED DEPTH OF SETTING TENSIOMETERS

Irrigation Depth of Active Root Zone	Sh Te
Inches	
12	
18	
24	
36	
48 or more (deep)	

1/ Only one tensiometer is recommended fo

g. The tensiometer may be installed in an auger hole several times larger than the diameter of the tensiometer. The cup should be pushed into the soil at the bottom of the hole, if it is soft enough. If the soil is too hard, it may be softened by water or a small hole can be made to receive the cup. The hole should be refilled in layers and compacted around the tensiometer tube. A special tool supplied by the manufacturer may be used to install the tensiometer. It is important to get good soil contact.

h. The above-ground parts of the tensiometer should be shielded from the sun to avoid a "thermometer" effect.

i. Readings should be examined carefully to detect the effect of a leak. A leaky tensiometer can give misleading results. The tensiometer should be kept filled with deaired (boiled) water or serviced regularly with deairing equipment.

j. Tensiometer readings should be correlated with the total soil water content in the soil profile at each station. This can be done by using the gravimetric method in Paragraph 6. Gravimetric measurements should be made for several different tensiometer readings and plotted on a graph. Figure A-1 shows an example of tensiometer readings versus soil water content in the root zone.

k. To schedule irrigation it is necessary to know which tensiometers should be used at a given site. The greatest soil suction will occur near the soil surface where the roots are most active. This may cause the activity of the soil water to decrease so rapidly that the range of operation of the tensiometer will be exceeded. This will cause air to enter the instrument.

   (1) In sandy soils, tensiometers in the active root zone should be used to schedule irrigation.

   (2) For clayey soils, the soil suction will usually exceed the operating range of the instrument before it is necessary to irrigate. The graph in Figure A-2 shows that it takes about 2.0 bars (200 centibars) of suction to reach a 50 percent water depletion level for a clay. At 0.8 bar or 80 centibars the water depletion level would be about 25 percent. This makes it necessary to use the lower tensiometers in the root zone to schedule irrigation.

   (3) Soil suction values that indicate need for irrigation will differ for the different soils. A guide for interpreting tensiometer readings is given in Table A-3.

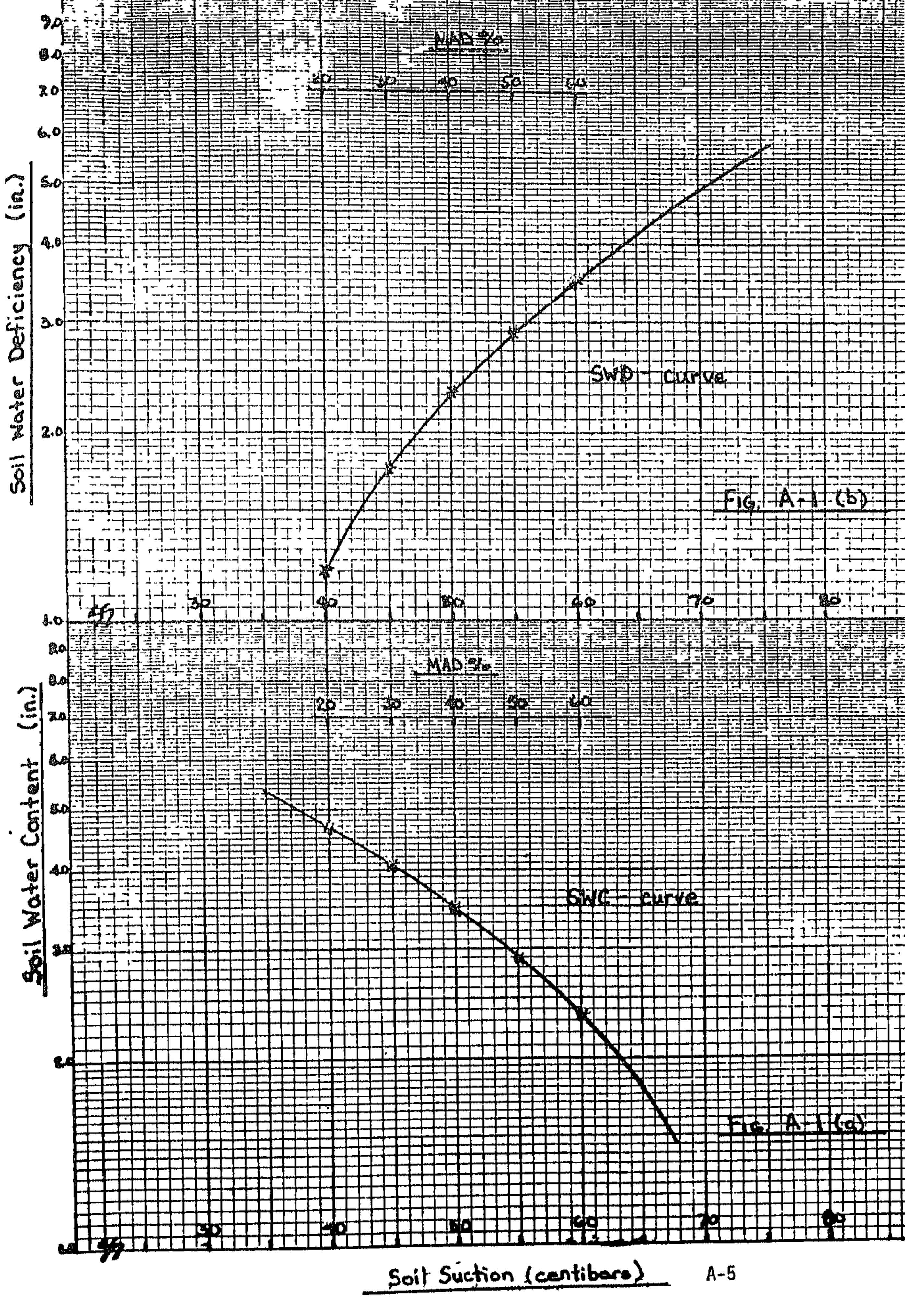
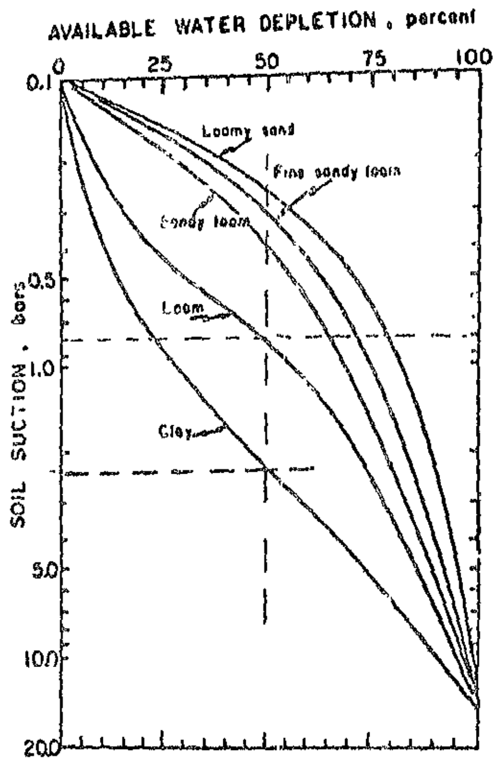


Fig. A-1 (b)

Fig. A-1 (a)

Figure A-2



Water retention curves for several soils plotted in terms of percent available water removed, redrawn with change in scale from Richards and Marsh (1961) and Taylor (1965).

Table A-3. INTERPRETATION OF TENSIOMETER READINGS

* Dial Reading Inches of Mercury	* Dial Reading Centibars	Interpretation
Nearly Saturated	0	Near saturated soil often occurs for a day or two following irrigation. Danger of water-logged soils, a high water table, poor soil aeration, or the tensiometer may
3	10	have broken tension, if readings persist.
Field Capacity	11	Field capacity. Irrigations discontinued in this range to prevent waste by deep percolation and leaching of nutrients
6	20	below the root zone. Sandy soils will be at field capacity in the lower range,
9	30	clayey soils will be at field capacity in the upper range.
Irrigation Range		Usual range for starting irrigations. Soil aeration is assured in this range. In general, irrigations start at readings of 30-40 in sandy textured soils (loamy
12	40	sands and sandy loams). Irrigations usually start from 40-50 on loamy soils, (very fine sandy loams and silt loams).
15	50	On clay soils (silty clay loams, silty clays, etc.) irrigations usually start from 50-60. Starting irrigations in
18	60	this range insures maintaining readily available soil moisture at all times.
Dry		This is the stress range. However, crop is not necessarily damaged or yield reduced.
21	70	Some soil moisture is readily available to the plant but is getting dangerously low for maximum production.
24	80	Top range of accuracy of tensiometer, readings above this are possible but the tensiometer will break tension between 80 to 85 centibars.

* Indicative of soil conditions where the tensiometer is located. Judgment should be used to correlate these readings to general crop conditions in the field.

3. Electrical resistance blocks

a. Electrical resistivity can be used to measure a change in soil water content. The equipment used to measure changes in soil water content consists of a portable resistance meter and electrodes inbedded in small blocks.

b. The blocks consist of permanently embedded electrodes in materials such as nylon, fiberglass, or gypsum. The electrodes are attached to lead wires which are plugged into a meter. When the blocks are placed in contact with the soil, the moisture content of the block tends to equal the moisture content of the soil. Because the electrical resistance of the electrodes in the block varies with the moisture content, a measurement of electrical resistance by the meter is a good indication of the soil moisture content. The drier the soil, the greater the electrical resistance, and vice versa. This method will work satisfactorily in any soil that does not exhibit saline or alkaline problems.

c. The location and depth of installation of these blocks is the same as for tensiometers. The gypsum blocks should be placed in the soil, in the rooting zone of the crop as early in the season as is practical and left in the soil throughout the growing season. The following procedure is suggested for installing the blocks.

(1) The electrical resistance blocks should be thoroughly soaked in a pail of water before installing (follow manufacturer's recommendations for soaking time). Soaking removes air from the blocks and insures accurate readings of the soil moisture.

(2) A soil probe or auger can be used to bore a hole in the row slightly larger than the electrical resistance block. In row crops, the hole should be angled toward the furrow.

(3) The last 3 inches of soil removed from the hole should be crumbled and put back into the hole. About ½ cup of water should be poured into the hole so a slurry of mud is formed in the bottom.

(4) The blocks should be pushed into the hole with the soil probe, or ½ inch diameter electrical conduit, setting them solidly in the bottom with a firm push of the probe. Firm contact between the blocks and surrounding soil must be made.

(5) The hole should then be filled with soil, 3 or 4 inches at a time, tamping the soil firmly as the hole is filled.

(6) The wire leads from the blocks should be brought to be a single station, midway between the holes and tied to a stake with the wires separated. The wires should be color coded with colored plastic tubing or other means of identation.

d. Irrigations should be scheduled when the meter readings from the water control zone reach the desired level of soil water depletion using the calibration curve developed for a given site.

(1) Meter readings that indicate the need for irrigation will be different for various textured soils and MAD.

(2) There will be differences in electrical resistance readings due to the frequency of the A.C. resistance meters. Each company selling these meters for measuring soil water content has instructions which are provided with the meters. Because of these problems, it is desirable to develop site specific calibration curves. Curves for three different soils are as follows.

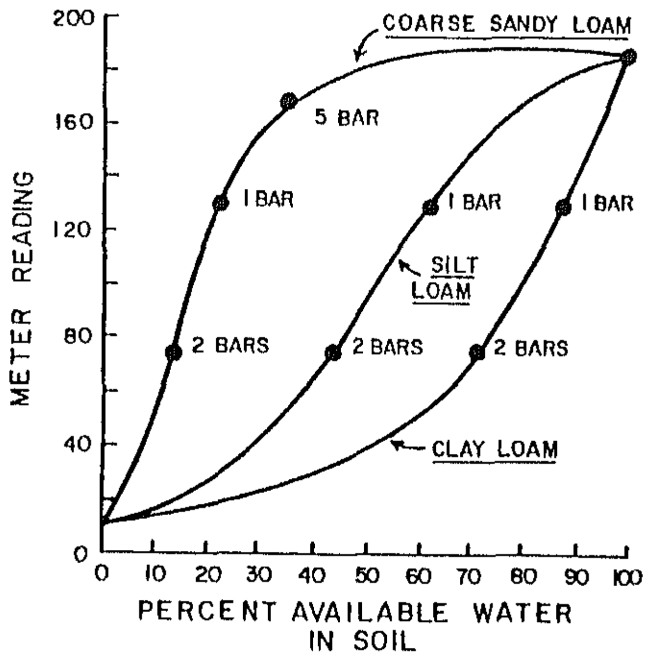


Figure A-3 Calibration curve for Delmhorst gypsum blocks for 3 different soil types.

APPENDIX B - IRRIGATION EVALUATION PROCEDURES

Contents

Figures

APPENDIX B - IRRIGATION EVALUATION PROCEDURES

1. General

a. The effectiveness of a farmer's irrigation water management practices can be determined by making field observations and evaluations. The results of these observations and evaluations are used to help the irrigator improve his water management techniques and/or upgrade his irrigation system. These improvements should save money by conserving water and energy, reducing nutrient losses, and improving crop yields. The following principles apply to all irrigation methods.

(1) Irrigation should be made in a timely manner so as to maintain a favorable soil water content for good crop growth. An exception may be made where the water supply is limited. In this situation, water should be applied in a manner that will maximize net income.

(2) The amount of water applied should be sufficient to bring the root zone profile up to field capacity. Center pivots may have difficulty meeting this requirement. In these cases, more frequent irrigations with a smaller application amount is practical. Recent research in the southeastern United States has revealed that shallow frequent applications may be more efficient and effective than attempting to bring the root zone profile up to field capacity. In cases of shallow control zones maintained at low-soil-water suctions on sandy soil, frequent small applications may be required to adequately meet crop water requirements without risking excessive leaching.

(3) The water should be applied at a rate that will not cause waste, erosion, or pollution.

b. An examination of a farmer's irrigation water managememt practices, then, should attempt to answer the following questions.

(1) Are irrigations being applied in a timely manner?

(2) What is the soil moisture deficiency?

(3) How much water is being applied?

(4) Is the irrigation causing excessive erosion?

(5) How uniformly is the applied water spread over the field?

(6) How much of the water is infiltrated into the soil?

(7) Is there excessive deep percolation and/or runoff?

(8) If so, how much deep percolation and/or runoff?

(9) Is there a pollution problem being caused by irrigation?

(10) What is the application efficiency and the uniformity of application?

(11) On a sprinkler irrigated field, is there translocation or surface runoff?

c. To answer some of the above questions, use should be made of the Irrigation Water Management sections on Irrigation Timing, Measuring Soil Water Content, and Procedures for Measuring Intake and Application Rates.

2. Sprinkler Irrigation Field Evaluation Procedure.

a. Center Pivot. It is good practice to occasionally test the performance of a center-pivot system to check on the uniformity of application and flow characteristics.

(1) Information required. Center pivot systems are propelled by using some of the water or by such independent power sources as electricity, oil hydraulics, or compressed air. Where water is used, it must be included as part of the total applied water; this somewhat lowers computed values of water use efficiency. When the water discharging from the pistons or turbines is distributed as an integral part of the irrigation pattern, its effectiveness should be included in the uniformity of application or the Distribution Uniformity (DU); otherwise, it should be ignored in the DU computations but should be included in computing the Application Efficiency of the Low Quarter (E_q).

The following information is required for evaluating center pivot irrigation systems.

(a) Rate of flow from the total system.

(b) Rate of flow required to propel the system if water driven.

(c) Depth of water caught in a radial row of catch containers.

(d) Travel speed of end drive unit.

(e) Lateral length to end drive unit and radius of the portion of the field irrigated by the center pivot.

(f) Width of the wetted strip at end drive unit.

(g) Operating pressure and diameter of largest sprinkler nozzles at the end of the lateral.

(h) Approximate differences in elevation between the pivot and the high and/or low points in the field and along the lateral at the test position radius (taken to within plus or minus 5 ft).

(i) Additional data indicated on Fig. B-1.

Accurate measurement of the flow rate into the system is needed for determining the E_q of the system; however, if no accurate flow metering device is at the inlet, the E_q can only be estimated.

(2) Equipment needed. The equipment needed is essentially the same as for the full evaluation of sprinkler-lateral systems.

(a) A pressure gauge (0-100 psi) with pitot attachment.

(b) A stopwatch or watch with an easily visible second hand.

(c) From 60 to 100 (depending on the lateral length) catch containers such as 1-quart oil cans or plastic freezer cartons.

(d) A 250-ml graduated cylinder to measure volume of water caught in the containers.

(e) A tape for measuring distances in laying out the container row and estimating the machine's speed.

(f) A soil probe or auger.

(g) A hand level and level rod to check differences in elevation.

(h) A shovel for smoothing areas to set catch containers and for checking profiles of soil, root, and water penetration.

(i) Fig. B-1 for recording data.

(j) Manufacturer's nozzle specifications giving discharge and pressure and the instructions for setting machine's speed.

(k) For water-driven machines which do not incorporate the drive water into the sprinkler patterns, a 2- to 5-gallon bucket and possibly a short section of flexible hoze to facilitate measuring the drive water discharge.

(3) Field procedure. Fill in the data blanks of Fig. B-1 while conducting the field procedure. In a field having a low-growing crop or no crop, test the system when the lateral is in a position where differences in elevation are least. In tall-growing crops, such as corn, test the system where the lateral crosses the access road to the pivot point.

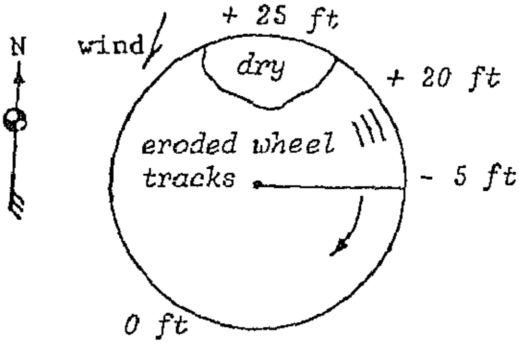
Figure B-1. CENTER PIVOT SPRINKLE IRRIGATION EVALUATION

1. Location *Field F202*, Observer *JK*, Date & Time *8-18-71 p.m.*

2. Equipment: make *HG 100*, length *1375* ft, pipe diameter *6 5/8* in

3. Drive: type *water* speed setting *--* %, water distributed? *yes*

4. Irrigated area = $\frac{3.14\ (\text{wetted radius } 1450 \text{ ft})^2}{43{,}560}$ = *152* acres

5. 

*Mark position of lateral direction of travel, elevation differences, wet or dry spots and wind direction.

Wind *6* mph, Temperature *90* °F

Pressure: at pivot *86* psi

at nozzle end *60* psi

Diameter of largest nozzle *1/2* in

Comments: *Sprinklers operating OK but end part circle sprinklers out of adjustment*

6. Crop: condition *corn, good except north edge*, root depth *4* ft

7. Soil: texture *sandy loam*, tilth *poor*, avail. moisture *1.0* in/ft

8. SMD: near pivot *0.5* in, at 3/4 point *0.5* in, at end *3.0* in

9. Surface runoff conditions at 3/4 point *slight*, and at end *moderate*

10. Speed of outer drive unit *45* ft per *10* min = *4.5* ft/min

11. Time per revolution = $\frac{(\text{outer drive unit radius } 1350 \text{ ft})}{9.55\ (\text{speed } 4.5 \text{ ft/min})}$ = *31.4* hr

12. Outer end: water pattern width *165* ft, watering time *39* min

13. Discharge from end drive motor *5.0* gal per *0.37* min = *13.5* gpm

14. System flow meter *115000* gallons per *10* min = *1150* gpm

15. Average weighted catches:

System = $\frac{(\text{sum all weighted catches } 257{,}708)}{(\text{sum all used position numbers } 2044)}$ = *126* ml = *0.50* in

Low 1/4 = $\frac{(\text{sum low 1/4 weighted catches } 57{,}974)}{(\text{sum low 1/4 position numbers } 518)}$ = *112* ml = *0.45* in

16. Minimum daily (average daily weighted low 1/4) catch:

$$\frac{(24 \text{ hrs operation/day}) \times (\text{low 1/4 catch } 0.45 \text{ in})}{(31.4 \text{ hrs/revolution})} = 0.34 \text{ in/day}$$

Figure B-1

CENTER PIVOT SPRINKLE IRRIGATION EVALUATION (Cont.)

17. Container catch data in units of *ml*, Volume/depth *250* ml/in

Span length *90* ft, Container spacing *22.5* ft

Evaporation: initial *150* ml *150* ml

final *-147* ml *-145* ml

loss *3* ml *5* ml, ave *4* ml = *0.016* in

Span no.	Container Position ~~H~~Number	X Catch	= Weighted Catch	Span No.	Container Position Number	X Catch	= Weighted Catch
1	1	*Start numbering at*		*10*	37	*118*	*4366*
1	2	*pivot end of inner*		*10*	38	*127*	*4816*
1	3	*span. Do not wait*		*10*	39	*115*	*4485*
1	4	*for completion of*		*10*	40	*147*	*5880*
2	5	*irrigation at first*		*11*	41	*127*	*5207*
2	6	*few containers.*		*11*	42	*122*	*5124*
2	7			*11*	43	*118*	*5074*
2	8			*11*	44	*144*	*6336*
3	9	*141*	*1269*	*12*	45	*112*	*5040*
3	10	*160*	*1600*	*12*	46	*124*	*5704*
3	11	*122*	*1342*	*12*	47	*126*	*5922*
3	12	*130*	*1560*	*12*	48	*151*	*7097*
4	13	*143*	*1859*	*13*	49	*120*	*5880*
4	14	*150*	*2100*	*13*	50	*122*	*6100*
4	15	*134*	*2010*	*13*	51	*115*	*5865*
4	16	*123*	*1968*	*13*	52	*143*	*7436*
5	17	*144*	*2448*	*14*	53	*124*	*6572*
5	18	*138*	*2484*	*14*	54	*114*	*7776*
5	19	*135*	*1565*	*14*	55	*115*	*6325*
5	20	*207*	*4140*	*14*	56	*160*	*8960*
6	21	*122*	*2562*	*15*	57	*120*	*8840*
6	22	*114*	*2508*	*15*	58	*110*	*6380*
6	23	*115*	*2645*	*15*	59	*109*	*6431*
6	24	*138*	*3312*	*15*	60	*117*	*7020*
7	25	*109*	*2725*	*16*	61	*85*	*5185*
7	26	*113*	*2938*	*16*	62	*194*	*12028*
7	27	*114*	*3078*	*16*	63	*148*	*9324*
7	28	*126*	*3584*	*End*	64	*82*	*5248*
8	29	*116*	*3364*		65		
8	30	*107*	*3210*				
8	31	*122*	*3782*				
8	32	*140*	*4480*				
9	33	*117*	*3861*				
9	34	*105*	*3570*				
9	35	*111*	*3885*				
9	36	*125*	*4428*				

Sum all: used position numbers *2044*, weig

Sum low 1/4: position numbers *518*, weig

As an example, a typical layout between wheel tracks for 90-foot spans and any type of drive can be accomplished by:

- o Placing the first container position 5 ft downstream from the pivot.

- o Setting container positions 2, 3, and 4 at 22.5-foot intervals. The fourth container position is now 17.5 ft from the wheel track of the first span.

- o Repeat the above procedure to the end of the actual wetted circle placing a catch container at each container position along the way.

However, to save time it is most convenient to leave out the first few containers adjacent to the pivot since the watering cycle is so long in this area. Typically, the containers under the first one or two spans are omitted with little adverse effect on the evaluation. A number should be assigned to each container position with a sequential numbering system beginning with 1 at the container position nearest the pivot point. Even the locations not having containers under the first spans should be numbered.

(b) Fill in the blanks (Fig. B-1) in parts 1 through 9, dealing with climatic conditions, machine and test specifications, topography, general system, soil moisture, and crop performance. Determine the irrigated area, part 4, in acres by first estimating the wetted radius of the irrigated circle.

(c) Determine the length of time required for the system to make a revolution by dividing the circumference of the outer wheel track by the speed of the end drive unit. (See parts 10 and 11 in which the conversion constant is $60/(2 \times 3.14) = 9.55$.)

- o Stake out a known length along the outer wheel track and determine the time required for a point on the drive unit to travel between the stakes. The speed of travel will be the distance divided by the number of minutes. An alternative method is to determine the distance traveled in a given time.

- o Since most machines have uniform span lengths except for perhaps the first span, the radius between the pivot and the outer wheel track can normally be determined by multiplying the span length by the number of spans.

(d) Estimate the width of the wetted pattern (perpendicular to the lateral) and the duration of time water is received by the containers near the end drive unit. The watering time is approximately equal to the pattern width divided by the speed of the end drive unit.

(e) On water-driven systems, number each drive unit (span) beginning with the one next to the pivot. Time how long it takes to fill a container of known volume with the discharge from the water motor in the outer drive unit and record on line 13. The exact method for doing this depends on the water motor construction, and it may require using a short length of hose.

(f) If the system is equipped with a flow meter, measure and record the rate of flow into the system on line 14 of Fig. B-1. Most standard flow meters indicate only the total volume of water that has passed. To determine the flow rate read the meter at the beginning and end of a 10-min period and calculate the rate per minute. To convert from cubic feet per second (or acre-inches per hour) to gpm, multiply by 450.

(g) At the time the leading edge of the wetted patterns reaches the test area, set aside two containers with the anticipated catch to check the volume of evaporation losses. Measure and record on line 17 the depth of water in all the containers as soon as possible and observe whether they are still upright; note abnormally low or high catches. The best accuracy can be achieved by using a graduated cylinder to obtain volumetric measurements. These can be converted to depths if the area of the container opening is known. For 1-quart oil cans, 200 ml corresponds to a depth of 1.0 in. Measure the catch of one of the evaporation check containers about midway during the catch reading period and the other one at the end.

Sample Calculation:	Utilization of center pivot field test data.

Given:

- The field data presented in Fig. B-1

Find:

- Use the field data to evaluate the system.

Calculation:

- The volumes caught in the containers must be weighted, since the catch points represent progressively larger areas as the distance from the pivot increases. To weight the catches according to their distance from the pivot, each catch value must be multiplied by a factor related to the distance from the pivot. This weighting operation is simplified by using the container layout procedure described earlier and Fig. B-1, part 17.

o The average weighted system catch is found by dividing the sum of the weighted catches by the sum of the catch positions numbers where containers were placed. Space for this computation is provided in parts 15 and 17.

o For the average minimum weighted catch, an unknown number of containers that represents the low 1/4 of the irrigated area must be used. The low 1/4 is selected by picking progressively larger (unweighted) catches and keeping a running total of the associated position numbers until the subtotal approximates 1/4 of the sum of all the catch numbers. The average weighted low 1/4 of the weighted catches by the sum of the associated catch position numbers. Space for this computation is also provided in parts 15 and 17.

o In order to determine whether the system is operating at acceptable efficiency, the losses to deep percolation and DU should be evaluated by:

$$DU = \frac{\text{average weighted low quarter catch}}{\text{average weighted system catch}} \times 100$$

which for the example problem (Fig. B-1, part 15) is:

$$DU = \frac{0.45}{0.50} \times 100 = 90 \text{ percent}$$

This is a reasonable value and is independent of the speed of revolution.

o It is useful to plot the volume of catch against distance from the pivot (Fig. B-2). Such a plot is useful for spotting problem areas and locating improperly nozzled or malfunctioning sprinklers. Usually there is excess water near each water-driven drive unit where the water is distributed as part of the pattern.

o If the system is operating on an undulating or sloping field and is not equipped with pressure or flow regulators, DU will vary with the lateral position. The DU will remain nearly constant if the differences in elevation (in feet) multiplied by 0.43 (to convert to an equivalent psi) do not exceed 20 percent of the pressure at the end sprinkler. Thus, for the example test the line position would have minimal effect on the DU since the pressure at the end sprinkler was 60 psi and the maximum elevation differences were only 25 ft, equivalent to 11 psi which is only 18 percent of 60 psi.

The E_a can be determined if the pivot point is equipped with an accurate flow measuring device. For the average low quarter rate caught use the average weighted low one-quarter of the catches expressed as a depth per revolution. The average depth of water applied per revolution is calculated by the formula: $Q = \frac{453\ Ad}{FH}$ where Q = system discharge capacity, gpm

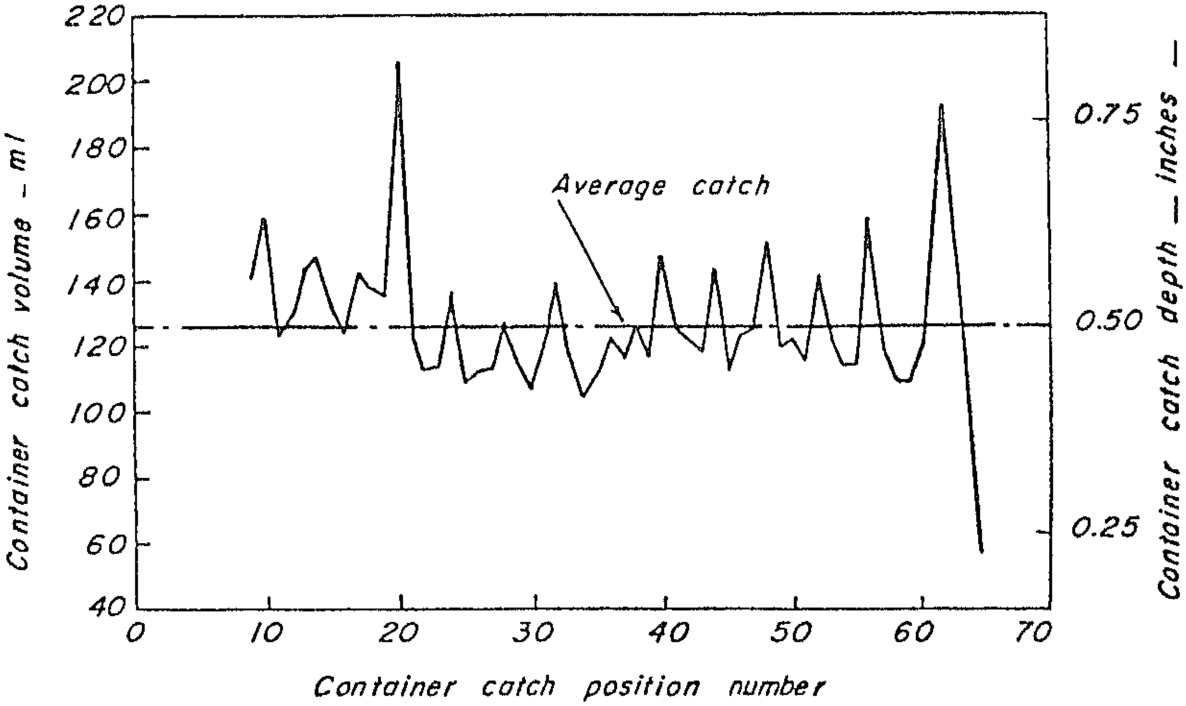


Figure B-2. Profile of container catch from center pivot sprinkler evaluation test. Pivot is located at 'O' position.

A = design area, acres

d = gross depth of application, in

F = time allowed for completion of one irrigation, days

H = actual operating time, hr/day

and from data computed on Fig. B-1, in parts 11, 14, and 4, the depth applied per irrigation (revolution) is:

$$d = \frac{31.4 \times 1,150}{453 \times 152} = 0.53 \text{ in}$$

$$E_q = DU \times \frac{\text{average weighted system catch}}{d}$$

$$= 90 \times \frac{0.50}{0.53} = 85 \text{ percent}$$

The small difference between DU of 89 percent and E_q of 85 percent indicates that evaporation losses are quite small and within the limits of accuracy of measurement.

The system flow rate and E_q can be estimated without a flow meter at the inlet. This is done by first estimating the gross application by adding the average depth caught and the estimated evaporation, which for the data recorded in Fig. B-1, parts 15 and 17, is 0.50 + .02 = 0.52 in per revolution. The flow in gpm; which was distributed through the sprinkler, can be estimated by:

$$\text{Distributed flow} = \frac{453 \times 152 \times 0.52}{31.4} = 1,133 \text{ gpm}$$

If water from the drive motor was not distributed, it must be added to the distributed flow to obtain the total system flow. The E_q is then computed as before by using the computed system flow. For the recorded data the drive water was included in the distributed flow and need not be computed. However, if it had not been included in the distributed flow, it should be estimated by:

$$\text{Drive flow} = \frac{\text{sum of drive unit numbers X gpm} \atop \text{flow from end water motor}}{\text{Number of drive units}}$$

for the 15 drive motors and a flow rate of 13.5 gpm from the end water drive motor:

$$\text{Drive flow} = \frac{120 \times 13.5}{15} = 108 \text{ gpm}$$

(4) Runoff. The computation of E_q is meaningful only if there is little or no runoff. Runoff and/or ponding may occur near the moving end of the system (Fig. B-2). Increasing the system's speed will reduce the depth per application and often prevent runoff. However, on some clay type soils, decreasing the system's speed and allowing the surface to become drier between irrigations will improve the soil infiltration characteristics and reduce runoff even though the depth per application is increased. Therefore, both increasing and decreasing the speed should be considered. Other methods for reducing runoff include:

(a) Using an implement called a pitter, which scrapes indentations in the furrows followed by small dikes every 2 or 3 ft.

(b) Reducing the total depth of water applied per week by turning the system off for a period after each revolution. (Automatic stop devices are available for many systems.) This allows the surface soil to become drier between irrigations and thus have a higher infiltration capacity. Careful planning is required in order to avoid extensive underirrigation which may reduce crop yields.

(c) Decreasing sprinkler nozzle diameters to decrease the system capacity and application rate. All the nozzles must be changed to maintain uniformity.

(d) Increasing system pressure and reducing nozzle sizes throughout the system to maintain the same system flow rate. This decreases the average drop size and thereby drop impact which reduces the surface sealing that restricts infiltration.

(e) Using special nozzles with pins to break up the jets and reduce drop sizes.

b. Periodic Move and Fixed System

Successful operation of sprinkle irrigation systems requires that the frequency and quantity of water application be accurately scheduled. Field application efficiency must be known to manage the quantity of application. Since system performance changes with time, periodic field checks are recommended. Data from the field evaluation of a periodic move sprinkle system is presented in Figure B-3. The procedure for collecting the data follows.

(1) Information required. The desired information includes:

(a) Duration of normal irrigations.

(b) Spacing of sprinklers along lateral lines.

(c) Spacing of lateral lines along the main lines.

(d) Measured depths of water caught in catch containers at a test location.

(e) Duration of the test.

(f) Water pressures at the sprinkler nozzles at the test location and along laterals throughout the system.

(g) Rate of flow from the tested sprinklers.

(h) Additional data specified on Figure B-3.

It is useful to know what wetting patterns the operation produces at different pressures and also operating pressures at the pump and along the mainline and laterals. General study of data obtained in the field enables determination of system DU and E_a. Further study enables determination of the uniformity and economics of the spacings and/or alternate sets, the economics of sizes of pipes used for mains and laterals, the desirability of using other operating pressures and other durations of application, and the effect of wind.

(2) Equipment needed. The equipment the evaluator needs is:

(a) A pressure gauge (0-100 psi) with pitot attachment.

(b) A stopwatch or watch with an easily visible second nd.

(c) A large container of known volume clearly marked (1 llon or larger for large sprinklers).

(d) A 4-foot length of flexible hoze having diameter preciably larger than the outside diameter of nozzles.

Figure B-3. SPRINKLER-LATERAL IRRIGATION EVALUATION

1. Location *Field C-22*, Observer *JLN*, Date *9-30-75*
2. Crop *Tomatoes*, Root zone depth *4.0* ft, MAD *50* %, MAD *4.4* in
3. Soil: texture *clay loam*, available moisture *2.2* in/ft, SMD *4.4* in
4. Sprinkler: make *Rain Bird*, model *29B*, nozzles *5/32* by ___ in
5. Sprinkler spacing *30* by *50* ft, Irrigation duration *23.5* hrs
6. Rated sprinkler discharge *4.4* gpm at *40* psi giving *0.28* in/hr
7. Lateral: diameter *2* in, slope *1½* %, Riser height *18* in
8. Actual sprinkler pressure and discharge rates:

	Sprinkler location number on test lateral						
	1	4	5	6	10	15	end
Initial pressure (psi)	45	40	40	40	39	40	
Final pressure (psi)	45		40		39	40	
Catch volume (gal)	1.0	1.0	1.0	1.0		1.0	
Catch time (min or sec)	0.21	0.22	0.22	0.22		0.22	
Discharge (gpm)	4.8	4.6	4.6	4.6		4.6	

9. Wind: direction relative to
   Part 10: initial ___, during ___, final ___
   Speed (mph): initial *2 ±*, during *5 ±*, final *5 ±*
10. Container grid test data in units of *ml*, Volume/depth *200* ml/in
    Container grid spacing *10* by *10* ft
    Test: start *2:55 pm*, stop *4:30 pm*, duration *1* hr *35* min = *1.58* hr

			32 / .10	68 / .21	77 / .24	90 / .28	6 73 / .23	66 / .21	9 / .03		ml / iph	
			35 / .11	66 / .21	84 / .16	100 / .31	100 / .31	52 / .16	3 / .01			
			32 / .10	50 / .16	60 / .11	104 / .32	99 / .31	48 / .15	12 / .04			
			31 / .10	74 / .23	88 / .27	104 / .32	5 86 / .22	56 / .17	11 / .03			
			27 / .08	64 / .20	80 / .25							
			20 / .06	49 / .16	59 / .19							

11. Evaporation container: initial _
12. Sprinkler pressures: max *45* psi
13. Comments *Test duration was too s*
1000 ml graduated cylinder. Win

(e) From 50 to 100 (or more depending on sprinkler size) catch containers such as 1-quart oil cans or plastic freezer cartons.

(f) A measuring stick (or ruler) to measure depth, or a 500-ml graduated cylinder to measure volume of water caught in containers.

(g) A soil probe or auger.

(h) A 50- or 100-foot tape for measuring distances in laying out catch container grid.

(i) A shovel for smoothing spots to set containers and for checking soil, root, and water penetration profiles.

(j) Figure B-3 for recording data.

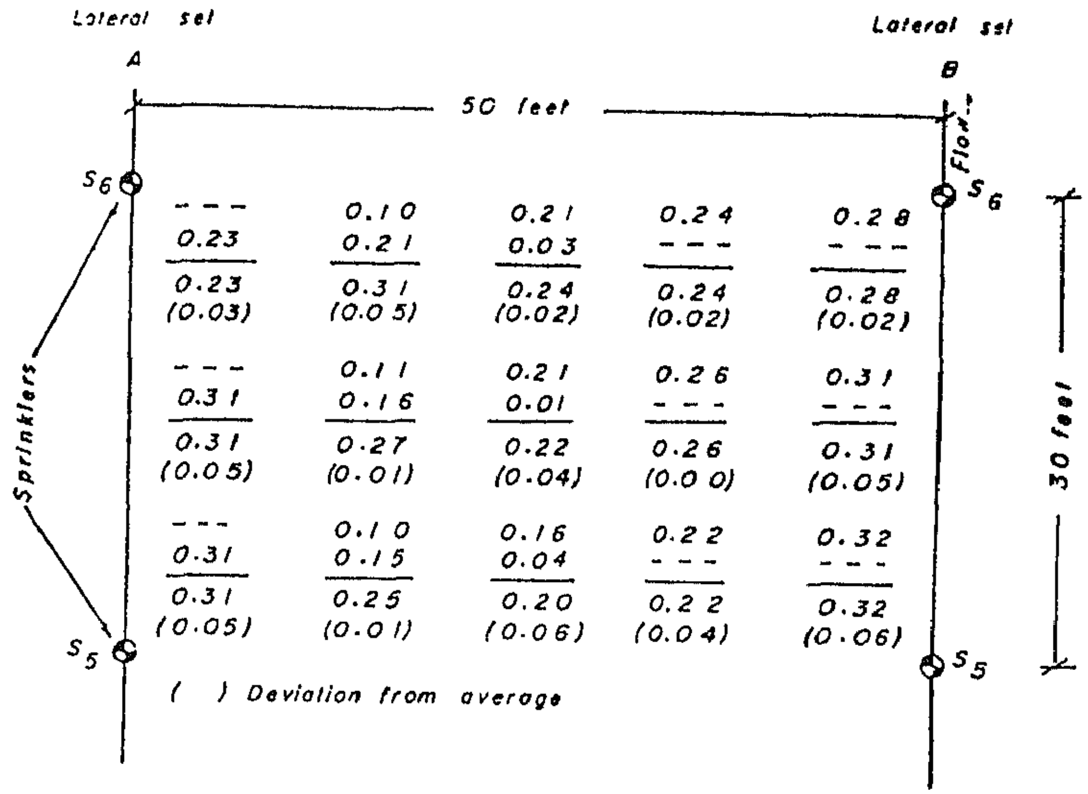
(k) Manufacturers' sprinkler performance charts showing the relationship between discharge, pressure, and wetted diameter plus recommended operating pressure ranges.

(l) A set of drill bits ranging in size from 3/64- to 1/4-inch in diameter in increments of 1/64-inch makes a handy set of feeler gauges to check nozzle wear.

(3) Field procedure. The information obtain from the following field procedure should be entered in a data sheet similar to B-3.

(a) Choose a location along a lateral for the test. It may be either a single location at which the pressure is typical (or average) for the entire system, or two locations near the ends of a lateral to permit study of effects of differences in pressure. Loss of pressure due to friction in a lateral that has only one size of pipe is such that about half of the pressure loss occurs in the first 20 percent of the length and over 80 percent of the pressure loss occurs in the first half of the lateral's length. (See Fig. B-5.) On a flat field the most representative pressure is about 40 percent of the distance from the inlet to the terminal end.

Figure B-4. Combind Catch Pattern (iph) Between Sprinklers 5 and 6 for a 50-foot Lateral Spacing



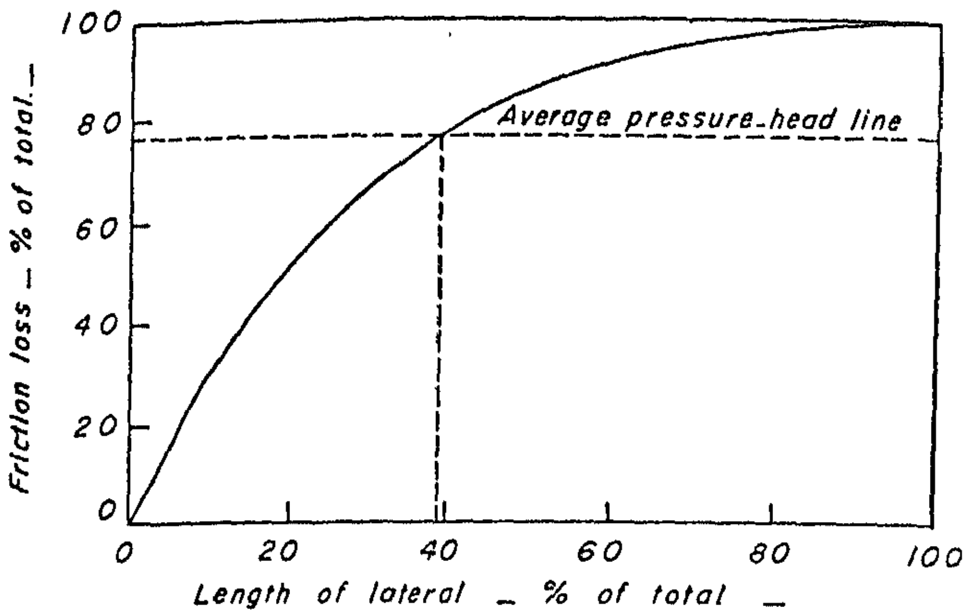


Figure B-5. Loss of pressure due to friction along a lateral having only one size of pipe.

(b) Set out at least 24 catch containers (see pattern in Fig. B-6) on a grid having a spacing not to exceed 10- by 10-foot for testing along a single lateral line. The catch containers' pattern should be laid out to cover two adjacent areas between three sprinklers since sprinklers may not apply water at precisely uniform rates. Each catch container is assumed to give the representative depth of catch over the square having the same dimensions as the can spacing in which it is centered. (See dotted grid lines in Fig. B-6.)

For solid set or block move systems where several adjacent laterals operate simultaneously, the catch containers should be placed in the area between two adjacent laterals. Caution should be exercised to allow for any water that could enter the test container area from adjacent blocks. These tests cannot be used to study other lateral spacings.

Each container should be located within a foot of its correct grid position and set carefully in an upright position with its top parallel to the ground; any surrounding vegetation that would interfere with a container should be removed. When it is windy, it may be necessary to fasten containers to short stakes with rubber bands, and weight them with a known depth of water or a stone (which is later subtracted from the total depth shown after the catch); or they may be set in shallow holes. The most accurate means for measuring the catch can be achieved volumetrically by using a graduated cylinder. These measurements can be converted to depths if the area of the container opening is known. For 1-quart oil cans, 200 ml corresponds to 1.00 in depth. Other suitable catch containers may be square or cylindrical plastic freezer containers with sides tapered slightly for nesting or any similar container.

Determine and record the container grid spacing and the ratio of volume to depth of catch. Also indicate the position of the lateral and record the location and position numbers of the sprinklers on the lateral.

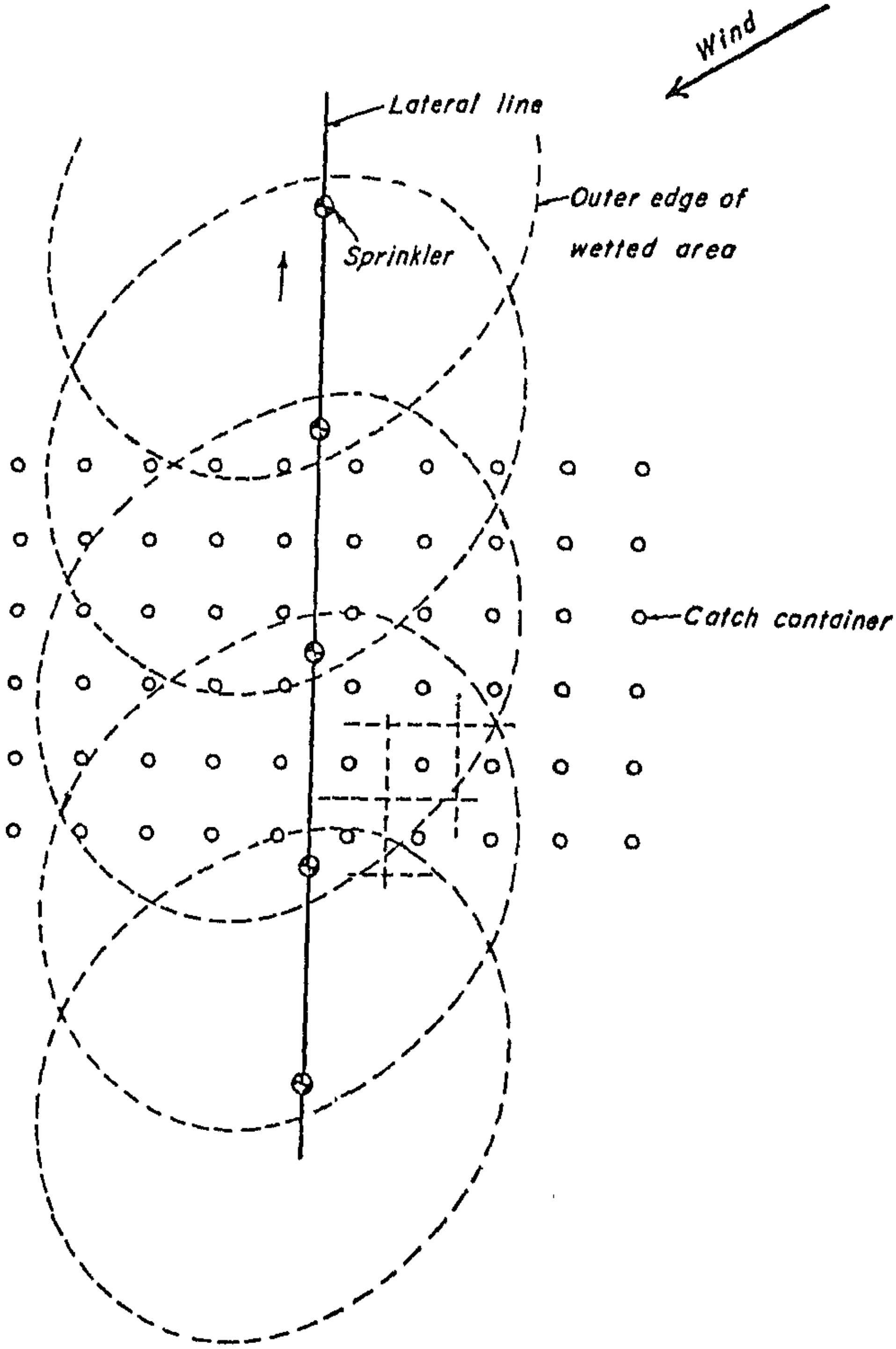
(c) Determine the soil texture profile and management allowed deficit, MAD, then estimate the available soil moisture capacity in the root zone (see Measuring Soil Water Content section of Irrigation Guide) and check the soil moisture deficit, SMD, in the catch area on the side of the lateral that was not irrigated during the previous set. These values should be recorded as shown on lines 2 and 3 of Fig. B-3.

(d) Check and record the make and model of the sprinkler and the diameter of the nozzles.

(e) Obtain the normal sprinkler spacing, duration, and frequency of irrigation from the operator and record them. The standard way of expressing the sprinkler grid spacing is __- by __-foot; this indicates the sprinkler spacing on the lateral and the spacing between laterals in that order.

(f) Read and record the rated sprinkler discharge, pressure, the computed average design application rate from the system design data and manufacturer's sprinkler catalogs.

Figure B-6. Layout of Catch Containers for Testing the Uniformity of Distribution Along a Sprinkler Lateral Line



(g) Check and record the size and slope of the lateral pipe and the height and erectness of the risers.

(h) Before starting the test, stop the rotation of the sprinklers at the test site to prevent water from entering the containers. A short piece of wire or stick wedged behind the swinging arm facilitates this.

Turn on the water to fill the lateral lines. When the test lateral is full, turn the pressure up slowly to observe the trajectory, breakup of drops, and effect of wind at different pressures. Then set the pressure at the value desired for the test.

Measure and record the pressure at the sprinklers to be tested at several places along the line and at both ends to observe the differences in pressure. Pressures should be checked at both the beginning and end of the test period and recorded on line 8. When measuring srinkler pressures, the pitot tube must be centered in the jet, which must impinge directly onto its tip. The tip may be rocked slightly. Record the highest pressure reading shown while the pitot tube is being held about 1/8-inch from the sprinkler nozzle.

Also on line 8, record how long it takes each sprinkler in this test area to fill the large container of known volume. Do this by slipping the short length of hoze over the sprinkler nozzle and collecting the flow in the container. To improve accuracy, measure the nozzle output several times and compute the average. (If the sprinkler has two nozzles, each can be measured separately with one hose.) Often the measured sprinkler discharge rate is greater than what the manufacturer specified at the given pressure. This occurs because sprinkler nozzles often erode during use and become enlarged, or because the hose fits too tightly and creates a syphoning action. You can check nozzle erosion with a feeler gauge such as a drill bit that has the diameter specified for the nozzle.

(i) Note the wind speed and direction and record the wind direction in part 9 by drawing an arrow relative to the direction of water flow in the lateral.

(j) Empty all catch containers before starting the test; start the test by releasing all sprinklers surrounding the test site so they are free to rotate and note the starting time on line 10.

(k) Set outside the catchment area a container holding the anticipated amount of catch to approximately check the volume of water lost by evaporation. (See Fig. B-3, line 11.)

(l) While the test is in progress, check sprinkler pressures at 20 to 40 systematically selected locations throughout the system (for example, at the two ends and quarter points along each lateral) and record the maximum, minimum, and average pressures encountered in part 12.

(m) Terminate the test by either stopping the sprinklers surrounding the test site in a position such that the jets do not fall into the containers, or by deflecting the jets to the ground. Note the time, check and record the pressure, and turn off the water. It is most desirable for duration of the test to be equal to the duration of an irrigation to get the full effect of wind and evaporation. Ideally minimum duration tests sould apply an average of about 0.5 in of water in the containers.

Measure the depth of water in all the containers and observe whether they are still upright; note any abnormally low or high catches. As shown in part 10, caught depths or volumes are recorded above the line at the proper gride point, which is located relative to the sprinkler and direction of flow in the pipe line. For long runs, where maximum depths exceed 2.0 in, a measuring stick provides suitable accuracy up to ±0.1 in.

(4) Utilization of field data. The utilization of the data was discussed in connection with the test data presented in Fig. B-4. The general procedure for utilizing the data is:

(a) Convert the depths or volumes of water caught in the containers to rates and record them (iph) below the line on the data sheet part 10. Assuming that the test is representative and that the next set would give identical results, the right-hand side of the catch pattern may, as if it were a subsequent set, be overlapped (or superimposed) on the left-hand side to simulate different lateral spacings. For lateral spacings that are whole units of the container spacings, the summation of the catches of the two sets represents a complete irrigation. (Fig B-4 illustrates overlapping.) For very close lateral spacings, water may overlap from as many as four lateral positions. The above concept of overlapping is not suggested where winds are likely to change appreciably between subsequent lateral sets. It is most valid for 24-hour sets.

(b) In order to determine whether sprinklers are operating at acceptable efficiency, the System DU and CU should be evaluated. The system DU is based on the average rate or depth recorded for the lowest one-fourth of the catch locations; hence, about 1/8 of the area may actually have received slightly less water. If an individual low value was due to a poor field measurement, perhaps no area actually received less. If the average low quarter depth infiltrated just matches the SMD, the percent of the infiltrated water going too deep would be approximately equal to 100 - system DU. (A similar relationship exists for CU.)

(c) The potential system application efficiency, E_q and E_h, should be determined in order to evaluate how effectively the system can utilize the water supply and what the total losses may be. The total amount of water required to irrigate the field fully can be estimated.

The E_q and E_h values are always a little lower than the DU and CU of a sprinkle irrigation system because the average water applied is greater than the average water caught. The difference between the average water applied and the water caught or received is an approximation of losses due to evaporation and drift plus loss of water due to some of the area's being ungauged and some evaporation from the gauge cans. The system E_q and E_h indicate how well the tested sprinklers are able to operate if they are run the correct length of time to satisfy the SMD or MAD. It is, therefore, a measure of the best management can do and should be thought of as the potential of the system within the limit that the test represents the whole field.

The effective portion of applied water, R_e, can be determined from the field data by:

$$R_e = \frac{\text{average catch rate (or depth)}}{\text{application rate (or depth)}}$$

$$= \frac{\text{average catch rate}}{96.3\ q/(S_1 \times S_m)}$$

where

q = average sprinkler discharge rate, gpm

S_1 = sprinkler spacing on the lateral, ft

S_m = lateral spacing along the main, ft

c. Traveling Sprinkler

The following procedures are designed mainly to check the uniformity and efficiency of irrigation across the travel paths. However, the nature of the operation and the large size of the sprinklers tend to reduce the quality of irrigation around field boundaries. It is particularly difficult to obtain high quality irrigation at the ends of the towpaths unless special control systems are used on the sprinkler, and on small fields this is an appreciable area--as much as 200 feet on each end.

If the traveling unit is powered by a water piston, the expelled water should not be included in evaluating the DU but should be included in computing the AELQ and PELQ.

DU - "Distribution Uniformity" indicates the uniformity of infiltration (or application in the case of sprinkle or trickle irrigation) throughout the field and is expressed as a percent relating the average depth infiltrated in the lowest one-quarter of the area to the average depth of water infiltrated.

AELQ - "Application Efficiency of Low Quarter" indicates the actual efficiency being achieved with a given system and is expressed as a percent relating the average low quarter depth of water stored in the root zone to the average depth of water applied.

PELQ - "Potential Application Efficiency of Low Quarter" is the measure of how well a system can perform under reasonably good management when the desired irrigation is being applied and is expressed as a percent relating the average low quarter depth infiltrated when equal to MAD to the average depth of water applied.

(1) Information required. The following information is required for evaluating traveling sprinkler irrigation sytems:

(a) Frequency of normal irrigations.

(b) MAD and SMD.

(c) Nozzle diameter and type for estimating system's flow rate.

(d) Pressure at the nozzle.

(e) Depth of water caught in catch containers.

(f) Travel speed when the unit is at the test location and extreme ends of the towpaths.

(g) Spacing between towpaths.

(h) Rate of discharge from water piston (if applicable).

(i) Additional data indicated on Fig. B-7.

An accurate estimate for the flow rate from the nozzle is necessary for calculating the PELQ and AELQ of the system. A good way to estimate this flow is to use the sprinkler performance chart provided by the manufacturer. A typical performance chart gives the rate of sprinkler discharge and diameter of coverage for various nozzle sizes at different pressures.

(2) Equipment needed. The equipment the evaluator needs is:

(a) A pressure gauge (0-150 psi) with pitot tube attachment.

(b) A stopwatch or watch with an easily visible second hand.

(c) Approximately 60 catch containers such as 1-quart oil cans or plastic freezer cartons.

(d) A 500-ml graduated cylinder to measure volume of water caught in the containers.

(e) A 50- or 100-foot tape for measuring distances in laying out the lines of containers and estimating machine's speed.

(f) A soil probe or auger.

(g) Manufacturer's sprinkler performance chart giving the relationship between discharge, pressure, and wetted diameter plus recommended operating pressure range. Also speed specifications and setting instructions for the traveling vehicle.

(h) A shovel for smoothing areas to set catch containers and for checking profiles of soil, root, and water penetration.

(i) A hand level to check differences in elevation.

(j) Fig. B-7 for recording data.

(k) For travelers powered by a water piston, a 2- to 5-gallon bucket and possibly a short length of flexible hoze to facilitate measuring the piston discharge.

(3) Field procedure. Fill in the data blanks of Fig. B-7 the field procedure progresses. Choose a test location about midway along the towpath where the traveler operates. The location should be far enough ahead of the sprinkler so no water reaches the test area before the catch containers are set up. It should be far enough from the outer end of the path so that the back (or trailing) edge of the

Figure B-7. TRAVELING SPRINKLER IRRIGATION EVALUATION

1. Location *Field 200*, Observer *JK*, Date *7/5/74*
2. Crop *Corn*, Root zone depth *4.0* ft, MAD *35* %, MAD *2.1* in
3. Soil: texture *fine sandy loam*, available moisture *1.5* in/ft
4. SMD: near tow path *2.1* in, at 1/4-point *2.2* in, at mid-point *3.7* in
5. Sprinkler/Traveler makes and models *Nelson 201* / *Heinzman 6645*
6. Nozzle: size *1.5* in, type *ring*, pressure *100* psi, discharge *500* gpm
7. Hose: length *660* ft, diameter *4* in, type *lay-flat*
   inlet pressure *137* psi, outlet pressure *110* psi
8. Drive: type *turbine*, discharge (if piston) *--* gal/ *--* min = *-* min
9. Towpath: spacing *330* ft, length *1320* ft, slope ± *0* %
10. Evaporation loss: (*200* ml catch = 1.0 in)
    cup #1 initial - final volume = *500* - *470* = *30* ml
    cup #2 initial - final volume = *500* - *482* = *18* ml
    average evaporation loss = *24* ml = *0.1* in
11. Traveler speed check at:
    beginning *9.5* ft/ *10* min = *0.95* ft/min
    at test site *10.0* ft/ *10* min = *1.0* ft/min
    terminal end *10.2* ft/ *10* min = *1.02* ft/min
12. Total: discharge *500* gpm, pressure loss *37* psi
13. Average application rate:

$$\frac{96.3 \times (\text{sprinkler discharge } \mathit{500} \text{ gpm}) \times 360}{(\text{towpath spacing } \mathit{330} \text{ ft})^2 \times (\text{wet sector } \mathit{345}\ °)} = \mathit{0.46} \text{ in/hr}$$

14. Average depth applied:

$$\frac{96.3}{60} \times \frac{(\text{sprinkler plus piston discharge } \mathit{500} \text{ gpm})}{(\text{path spacing } \mathit{330} \text{ ft}) \times (\text{travel } \mathit{1.0} \text{ ft/min})} = \mathit{2.43} \text{ in}$$

Average overlapped catches:

$$\text{tem} = \frac{(\text{sum all catch totals } \mathit{74.87} \text{ in})}{(\text{number of totals } \mathit{33})} = \mathit{2.27} \text{ in}$$

$$\text{Low } 1/4 = \frac{(\text{sum of low } 1/4 \text{ catch totals } \mathit{12.91} \text{ in})}{(\text{number of low } 1/4 \text{ totals } \mathit{8})} = \mathit{1.61} \text{ in}$$

16. Comments (wind drift, runoff etc.): *no evidence of serious wind drift or runoff; crop was stunted midway between paths*

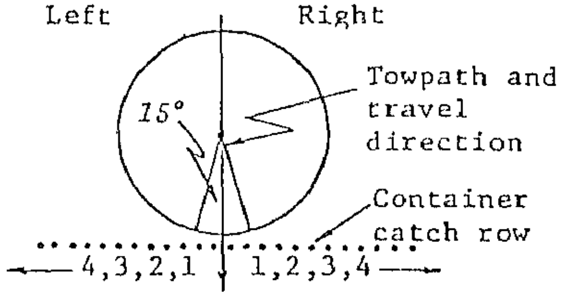
Figure B-7. TRAVELING SPRINKLER IRRIGATION EVALUATION (Cont.)

17. Container test data in units of ml, Volume/depth 200 ml/in

Wind: speed 5-10 mph

direction

Note part circle operation and the dry wedge size in degrees



Left side of path: Start with number 1 opposite the towpath spacing and number down

Right side of path: Start with number 1 at bottom of column and number up

Path Spacing feet	Container Catch Volume: Left side of path: Catch No.	Catch	Right side of path: Catch No.	Catch	Right plus Left Side Catch Totals: ml	inches
330	1	560	33		560	2.80
320	2	540	32		540	2.70
310	3	510	31		510	2.55
300	4	490	30		490	2.45
290	5	505	29		505	2.53
280	6	475	28		475	2.38
270	7	480	27		480	2.40
260	8	460	26		460	2.30
250	9	430	25		430	2.15
240	10	410	24		410	2.05
230	11	370	23		370	1.85
220	12	325	22		325	1.63
210	13	305	21		305	1.53
200	14	345	20		345	1.73
190	15	335	19		335	1.68
180	16	310	18		310	1.55
170	17	305	17		305	1.53
160	18	290	16	35	325	1.62
150	19	250	15	75	325	1.62
140	20	230	14	120	350	1.75
130	21	215	13	215	430	2.15
120	22	165	12	365	530	2.65
110	23	95	11	410	505	2.52
100	24	65	10	515	580	2.90
90	25	25	9	540	565	2.82
80	26	--	8	525	525	2.62
70			7	500	500	2.50
60			6	490	490	2.45
50			5	470	470	2.35
40			4	490	490	2.45
30			3	540	540	2.70
20			2	605	605	3.02
10			1	625	625	3.12

Sum of all catch totals 74.87

Sum of low 1/4 catch totals 12.91

sprinkler pattern passes completely over it before the sprinkler reaches the end of the towpath. A good location for the test area is along the main line where an access road is usually provided. In tall growing crops such as corn, an access road is the only practical location for the test.

(a) Set out a row of catch containers 10 feet apart across the towpath (see Fig. B-8); the containers that are adjacent to the towpath should be set on both sides of the towpath about 5 feet from the center of the patch. The outer containers should be at the edges of the wetted strip. It is good practice to provide at least two extra containers on both ends of the container row to allow for changes in wind direction or speed.

(b) Fill in the data blanks about the crop and soil (parts 2 and 3 of Fig. B-7).

(c) Check the SMD at the following locations: 10 feet from the towpath; one-fourth of the distance to the next towpath; and midway between the towpath in use and the one to be used next. Enter these SMD data in part 4.

(d) Note the make and model of the traveler, the sprinkler, type of nozzle (orifice ring or taper bore), and nozzle diameter. (It is also good practice to measure the nozzle size after the system is turned off. This is done to check for nozzle erosion so the estimated flow rate can be adjusted if necessary.) Enter this information in parts 5 and 6.

(e) Check the hose length and diameter, also the inlet and outlet pressures of the hose, if feasible. Record in part 7.

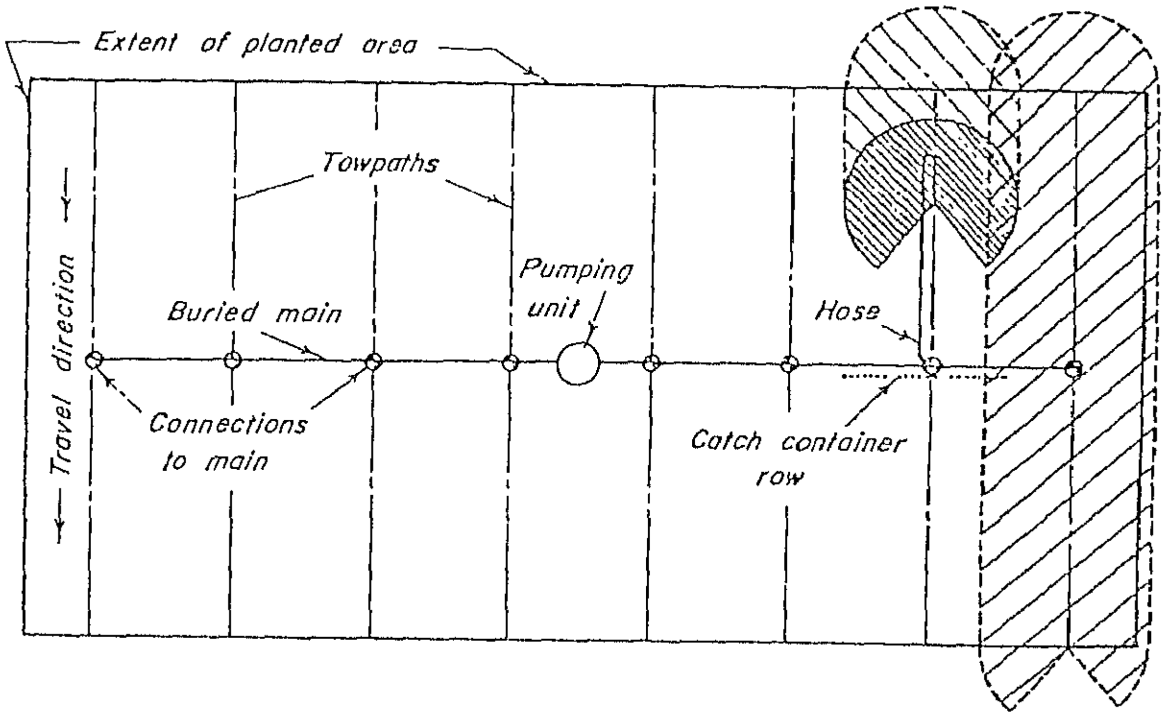
(f) Check and record in part 8 the type of drive used in the traveler. In evaluating water-piston powered travelers to estimate the drive flow, determine how long it takes the discharge from the piston to fill the bucket (or jug) of known volume.

(g) Measure and record the spacing between towpaths and the towpath length and general slope in part 9.

(h) Set out two containers with the anticipated catch to check the volume of evaporation losses. The first container should be set out when the wetted pattern first reaches the catch row and the second container when the sprinkler vehicle reaches the row. Record these catches in part 10 which is set up to record these data.

(i) Determine the travel speed of the unit (ft/min) as it passes over the row of containers. This speed should also be checked at the extreme ends (beginning and terminal on Fig. B-7) of the towpath and recorded in part 11. To do this, stake out a known length, say 10

Figure B-8. Typical Layout for Traveling Sprinklers Showing Location of Catch Container Line for Evaluating the Distribution Uniformity



feet, and determine the time required for a point on the vehicle to travel between the stakes. An alternate method is to determine the distance traveled in a given time, say 10 minutes.

(j) Check and record in part 6 the pressure at the sprinkler nozzle when it is about directly over the catch row and estimate the sprinkler discharge from the manufacturer's performance chart.

(k) Estimate and record in part 12 the total discharge from the traveler by adding the sprinkler nozzle and piston discharges. Also estimate and record the total pressure loss through the hose and sprinkler.

(l) Note in part 17 the general test conditions including: wind speed and direction, angle degrees of the dry wedge of part-circle sprinkler operation, wet or dry spots, and runoff problems.

(m) Measure and record in part 17 the depth of water in all the containers as soon as possible and observe whether they are still upright; note any abnormally low or high catches. Then measure and record in part 10 the catch in the two evaporation check containers after the last container in the row has been recorded.

(n) Note any special comments such as runoff, test problems, and crop water stresses in part 16.

(o) Do the computational work required in parts 17 and 13 through 15 of Fig. B-7.

Part 17 of Fig. B-7 is designed to simplify the procedure of overlapping the catches to simulate a complete irrigation between adjacent towpaths. To use the form, number the containers from the towpath outward beginning with 1, 2, 3, etc., to the right and to the left looking opposite to the direction of travel. Enter the container numbers and catch volumes as follows: for the left side data start numbering with container 1 opposite the actual towpath spacing (which for the example field evaluation is 330 feet) and number downward; and for the right side data start the numbering with container 1 opposite the towpath spacing of 10 feet and number upward.

(4) Utilization of field data. Data used in computations in the following pages were recorded in evaluation of a traveling sprinkler system in a corn field (Fig. B-7).

Assuming the test is representative and that the next run would give identical results, the left-hand side of the container catch volumes may be overlapped on (added to) the right-hand side. (See Fig. B-8.) Fig. B-7 is designed to simplify this operation.

The overlapped data totals provide an estimate of the profile of the depth of irrigation water between adjacent towpaths. For computations

of DU, PELQ, and AELQ that follow, it is assumed that this depth profile represents the distribution throughout the field. In other words, the assumption is that the depth profile across the strip between towpaths is the same along the entire strip. This is obviously subject to question because of discontinuities at the path ends, changes in travel speeds, variations in pressure due to elevation, and changes in wind speed and direction.

(5) Distribution uniformity. In order to determine whether the system is operating at an acceptable and economical efficiency, the DU should be evaluated. For the sample test using the average and low one-quarter catch data from part 15 of Fig. B-7 is:

$$DU = \frac{1.61}{2.27} \times 100 = 71 \text{ percent}$$

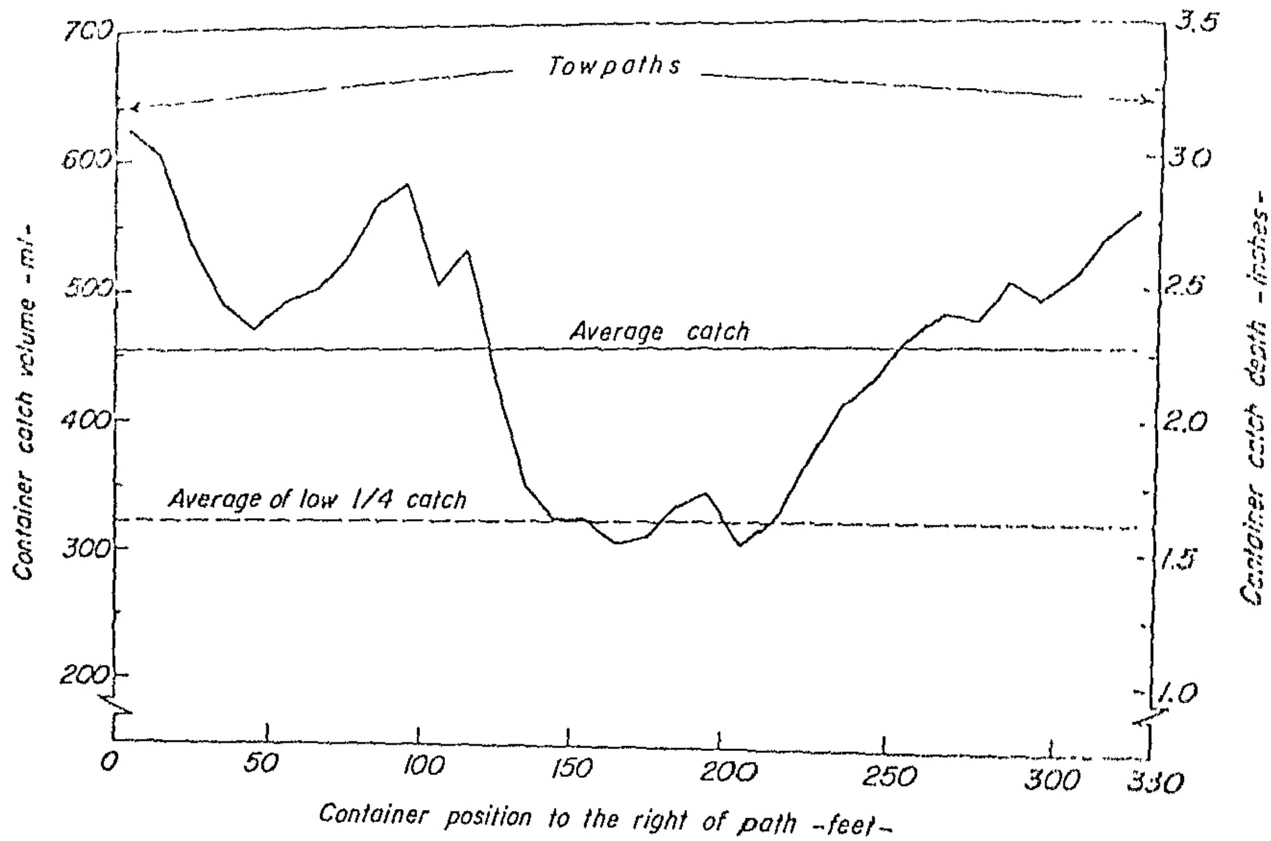
This is a fair value for a traveler system with widely spaced towpaths and is generally independent of the speed of travel.

It is useful to plot the depth of catch along the distance between towpaths (see Fig. B-9) as a means for spotting problem areas. Note that the plotted points represent the depth of catch at the midpoint of each 10-foot interval between adjacent towpaths. Fig. B-9 shows that either the towpaths are too far apart, which results in a shallow wetted depth midway between towpaths, or that the angle of the part circle is set too narrow. The effect of narrowing the spacing between towpaths can be measured by using a blank copy of Fig. B-7 , part 17, and repeating the above procedure with the same catch data and the new spacing. Widening this angle of the dry wedge would reduce the depth of water applied near the paths and would increase the depth of water applied midway between towpaths; but to measure the effect of widening the angle requires another catch test run.

The check of travel speed shows that the unit moves faster toward the terminal end of the towpath run. (See sample Fig. B-7, part 11.) This change in speed is caused by the interaction of the buildup of cable on the winch reel and the increased drag exerted by the hose as the unit moves from the beginning to the terminal end of the towpath. Fortunately, these two factors somewhat offset each other, and in the operation reported here the unit was traveling only 2 percent faster at the terminal end than in the test area and 5 percent slower at the beginning end. (See Fig. B-8.) These changes of speed would lower the DU over the entire strip by about three-eights of the total percent speed change, i.e., 3/8 x (2 + 5) or less than 2 percent.

Since the nozzle pressure is normally near 100 psi, differences in elevation are usually not great enough to affect DU appreciably. Only differences in elevation along the towpaths are of concern because valves can adjust hose inlet pressures. However, even with a difference of 40 to 50 feet in elevation along the towpath, the DU decreases by only about 4 percent.

Figure B-9. Profile of Overlapped Container Catch Data From Traveling Sprinkler Evaluation



Changes in wind speed and/or direction can greatly affect DU, especially if the wind direction changes appreciably during the operation in adjacent towpaths (blows from the left in Fig. B-8 one day and from the right the next day). However, if the system is managed to operate approximately 24 hours in each towpath, as in the example test, wind problems are minimized. The traveler is in about the same relative position along adjacent towpaths at a given time of day, when wind speed and direction are most likely to be similar.

(6) Potential application efficiency (PELQ) should be determined in order to evaluate how effectively the system can utilize the water supply and what the water losses may be, then the total amount of water required to irrigate the field can be estimated. PELQ is calculated from the ratio of the average low-quarter depth caught in the containers to the average depth applied (rather than rates as used in other sprinkler system evaluations).

The average depth applied, D (in inches), is calculated from a constant times the total traveler discharge (the sprinkler discharge plus the piston discharge, if the traveler is driven by water piston) divided by the towpath spacing and the sprinkler's travel speed.

$$D = \frac{96.3}{60} \times \frac{\text{sprinkler plus piston discharge (gpm)}}{\text{path spacing (feet)} \times \text{travel (feet/min)}}$$

From the sample data given in parts 9, 10, and 11, and computed in part 14 on Fig. B-7, the average depth applied is 2.43 inches. The PELQ with a low one-quarter depth of 1.61 inches is:

$$PELQ = \frac{1.61}{2.43} \times 100 = 66 \text{ percent}$$

This is a reasonable value for the central portion of a traveler irrigated field with such wide towpath spacings; however, the PELQ around the boundaries will be much lower.

(7) Application efficiency. Effectiveness of the use of the traveler system can be estimated by how much of the applied water is stored in the soil and available for consumptive use and by comparing the AELQ and the PELQ.

The fine sandy loam soils in the area tested hold about 1.5 inches per foot available moisture. Depth of the root zone of the corn was 4.0 feet at that time, and a 35 percent MAD was considered ideal. This gives an MAD of 2.1 inches. The field checks showed that SMD near the towpath and at the 1/4 point where 2.1 inches and 2.2 inches, respectively, while in the middle of the strip it was 3.7 inches.

The minimum depth of 1.6 inches was applied in the middle of the strip where the SMD was 3.7 inches (Fig. B-8 and B-9). Thus, the system did not apply a full irrigation; no water was lost to deep percolation in the low-quarter application area; and AELQ = PELQ = 66 percent.

Apparently much of the area had been receiving adequate irrigation because the SMD and MAD over much of the strip were less than or equal to the depth of application. However, underirrigation had created a cumulative deficit in the middle areas between towpaths. This deficit was beginning to affect the corn growth as evidenced by stunted plants midway between paths.

(8) Application rate. The gun sprinklers normally used on travelers produce a rather flat pattern of distribution. That is, if the traveler vehicle were standing still, the application depth or application rate over most of the wetted area would be fairly uniform. An estimate of the average application rate, R, in inches per hour can be obtained from a conversion constant times the flow (in gpm) from the sprinkler divided by the wetted area. The wetted area depends on the angle of the wet sector (for part-circle sprinklers).

$$R = \frac{96.3 \text{ x sprinkler discharge (gpm) x } 360}{\text{towpath spacing (feet)}^2 \text{ x wet sector (degrees)}}$$

For the sample evaluation (Fig. B-7, , parts 6 and 9), the sprinkler discharges 500 gpm and the towpath spacing is 330 feet with the part-circle sprinklers set for a 15° dry sector, i.e., 345° wet. The estimated average application rate computed in part 13 of Fig. B-7 is R = 0.46 in/hr. This is a fairly high application rate for the fine sandy loam soils which could cause infiltration and runoff problems in steeper areas or where the soil is in poor condition (tilth).

(9) Analysis and recommendations. Many of the observations and some recommendations that can be made from the additional data on Fig. B-7, plus the DU and PELQ computations have already been referred to here and in other sections about sprinkle evaluation.

(a) Operational checks. The pressure of 100 psi at the nozzle is ideal for good breakup of drops. The total recorded losses of 37 psi (10 psi in the drive turbine and 27 psi in the 4-inch by 660-foot flexible hose) are reasonable. (See Fig. B-7, parts 6, 7, and 12.)

(b) Runoff. Infiltration did not appear to be a problem. The fine sandy loam soils could receive the light application at 0.46 iph with no runoff, and the towpath remained relatively dry.

(c) Underirrigation. After reviewing the full value of the operation, it was concluded that the amount of underirrigation was reasonable. The area receives considerable summer rain which may offset the cumulative SMD along the center of the strips; furthermore, the large area of the field and the restricted supply of water made it impractical to increase the average depth of application very much. Only improvements in DU and possibly slightly higher flow rates would be practical.

(d) Improvements. The only major improvement necessary would be to increase the DU. However, it is not reasonable to narrow the towpath spacing during the growing season. If this spacing were reduced, the numbers of towpaths and consequently the number of days between irrigations would need to be increased.

Several practical possibilities for improving the DU might be tried in the following order:

- o Increase the angle of the dry area up to between 90° and 120°.

- o Try a taper bore nozzle, which would have a greater range for the same discharge and pressure.

- o Increase the nozzle size to the next larger sized ring nozzle.

(e) Edge effects. The outside towpaths of the present system are placed 150 feet inside the field boundaries. The field was laid out similarly to what appears in Fig. B-8. There were 8 towpaths across the 2,610-foot width of the field--2,640 feet less a 30-foot road right-of-way. Data on Fig. B-7, , part 17, indicate this layout should give a reasonable application (1.7 inches) on the downwind side but a very light (0.4 inch) watering along the upwind side.

The traveler started at one edge of the field and stopped at the opposite edge. This resulted in considerable overthrow but watered the ends of the field (Fig. B-8) fairly well. The full length of the 660-foot hose was needed because it had to be dragged through the 1,320-foot length of the towpaths.

The PELQ of 66 percent computed earlier was for the central portion of the field; however, because of poor uniformity along the boundaries where there is insufficient overlap, plus water that is thrown outside of the planted area (see Fig. B-8) the overall field efficiency is considerably lower. For the 80-acre field evaluated, the overall field PELQ was only estimated to be 52 percent. Much of this reduction in efficiency is due to poor uniformity along the edge of the field where [illegible] started and the edge where it stops (See Fig. B-8.)

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... ;ated in the midportions of the strips between towpaths. Changing ... of the dry area of the sprinkler or the type or size of the sprinkler ... may improve the DU.

... control systems which essentially eliminate the reduction in ... caused by the poor uniformity along towpath ends are in the pilot ... stage These control systems change the angle of the part ... sprinkler and the speed of travel upon leaving and approaching ... towpath ends. For the 80-acre field evaluated, such a control ... could increase the overall field PELQ by about 10 percent or up ... approximately 62 percent.

3. Trickle Irrigation Field Evaluation Procedure

Successful operation of trickle irrigation requires that the frequency and quantity of water application be accurately scheduled. The field emission uniformity, EU', must be known in order to manage the quantity of application. Unfortunately, EU' often changes with time; therefore, periodic field checks of system performance are necessary.

The data needed for fully evaluating a trickle irrigation system are available by determining:

1. Duration, frequency, and sequence of operation of normal irrigation cycle.

2. The S_{md} and M_{ad} in the wetted volume where

S_{md} - Soil moisture deficit is the difference between field capacity and the actual soil moisture in the root zone soil at any given time. It is the amount of water required to bring the soil in the root zone to field capacity.

M_{ad} - Management allowed deficit is the desired soil moisture deficit at the time of irrigation. It is expressed as a percent of the available water capacity (W_a) or the corresponding soil moisture deficit (S_{md}) related to the desired soil moisture stress for the crop-soil-water-climate system. Sprinkle and surface irrigation is usually scheduled when S_{md} equals M_{ad} but trickle irrigation is often scheduled with a much lower S_{md}. However, in humid areas supplemental irrigation depths are often applied to only partly replace S_{md} in order to leave some root zone capacity for storage of anticipated rainfall.

3. Rate of discharge at the emission points and the pressure near several emitters spaced throughout the system.

4. Changes in rate of discharge from emitters after cleaning or other repair.

5. The percent of soil volume wetted.

6. Spacing and size of trees or other plants being irrigated.

7. Location of emission points relative to trees, vines, or other plants and uniformity of spacing of emmision points.

8. Losses of pressure at the filters.

9. General topography.

10. Additional data indicated on Fig. B-10.

Figure B-10. TRICKLE IRRIGATION EVALUATION

1. Location ________________, Observer _______, Date ________________

2. Crop: type ___________, age _____years, spacing ___-by ____-feet
   root depth _____ft, percent area covered or shaded _____%

3. Soil: texture ________________, available moisture ________in/ft

4. Irrig: duration ___hrs, frequency ___days, M_{ad} ___%, ________in

5. Filter pressure: inlet ___psi, outlet ___psi, loss ________psi

6. Emitter: make _____________, type _______, point spacing _____ft

7. Rated discharge per emission point ________gph at ___________psi
   Emission points per plant ____, giving ___gallon per plant per day

8. Lateral: dia._____in, ______material___ length ____ft, spacing___ft

9. System layout, general topography, and test locations:

10. System discharge _____gpm, No. of manifolds _____ and blocks _____

11. Average test manifold emission point discharges at __________psi

$$\text{Manifold} = \frac{(\text{sum of all averages} \_\_\_\_\_\_ \text{gph})}{(\text{number of averages} \_\_\_\_\_\_)} = \_\_\_\_\_\_\_\_ \text{gph}$$

$$\text{Low } 1/4 = \frac{(\text{sum of low } 1/4 \text{ averages} \_\_\_\_\_\_ \text{gph})}{(\text{number of low } 1/4 \text{ averages} \_\_\_\_\_\_)} = \_\_\_\_\_\_\_\_ \text{gph}$$

12. Adjusted average emission point discharges at ______________psi
    System = (DCF _____) (manifold average _____gph) = ________gph
    Low 1/4 = (DCF ____) (manifold low 1/4 _____gph) = ________gph

13. Comments: ____
____
____

Figure B-10. TRICKLE IRRIGATION EVALUATION (Cont.)

14. Discharge test volume collected in ____ min (1.0 gph = 63 ml/min)

Location on Lateral		Lateral Location on the Manifold							
		inlet end		1/3 down		2/3 down		far end	
		ml	gph	ml	gph	ml	gph	ml	gph
inlet end	A B								
	Ave								
1/3 down	A B								
	Ave								
2/3 down	A B								
	Ave								
far end	A B								
	Ave								

15. Lateral inlet ____ psi ____ psi ____ psi ____ psi
closed end ____ psi ____ psi ____ psi ____ psi

16. Wetted area ____ ft^2 ____ ft^2 ____
per plant ____ % ____ %

17. Estimated average Smd in wetted

Equipment needed

The equipment needed for collecting the necessary field data is:

1. Pressure gauge (0-50 psi range) with "T" adapters for temporary installation at either end of the lateral hoses.

2. A stopwatch or watch with an easily visible second hand.

3. Graduated cylinder with 250 ml capacity.

4. Measuring tape 10 to 20 ft long.

5. Funnel with 3- to 6-in diameter.

6. Shovel and soil auger or probe.

7. Manufacturer's emitter performance charts showing the relationships between discharge and pressure plus recommended operating pressures and filter requirements.

8. Sheet metal or plastic trough 3 ft long for measuring the discharge from several outlets in a perforated hose simultaneously or the discharge from a 3-ft length of porous tubing. (A piece of 1- or 2-in PVC pipe cut in half lengthwise makes a good trough.)

9. Copies of Figure B-10 for recording data.

Field Procedure

The following field procedure is suitable for evaluating systems with individually manufactured emitters (or sprayers) and systems that use perforated or porous lateral hose. Fill in the data blanks of Form 7-11.1 while conducting field procedure.

1. Fill in parts 1, 2, and 3 of Figure B-10 concerning the general soil and crop characteristics throughout the field.

2. Determine from the operator the duration and frequency of irrigation and his concept of the M_{ad} to complete part 4.

3. Check and note in part 5 the pressures at the inlet and outlet of the filter and, if practical, inspect the screens for breaks and any other possibility for contaminants to bypass the screens.

4. Fill in parts 6, 7, and 8 which deal with the emitter and eral hose characteristics. (When testing perforated or porous tubing discharge may be rated by the manufacturer in flow per unit length.)

Locate four emitter laterals along an operating manifold (See 11); one should be near the inlet and two near the "third" he fourth near the outer end. Try to select a manifold

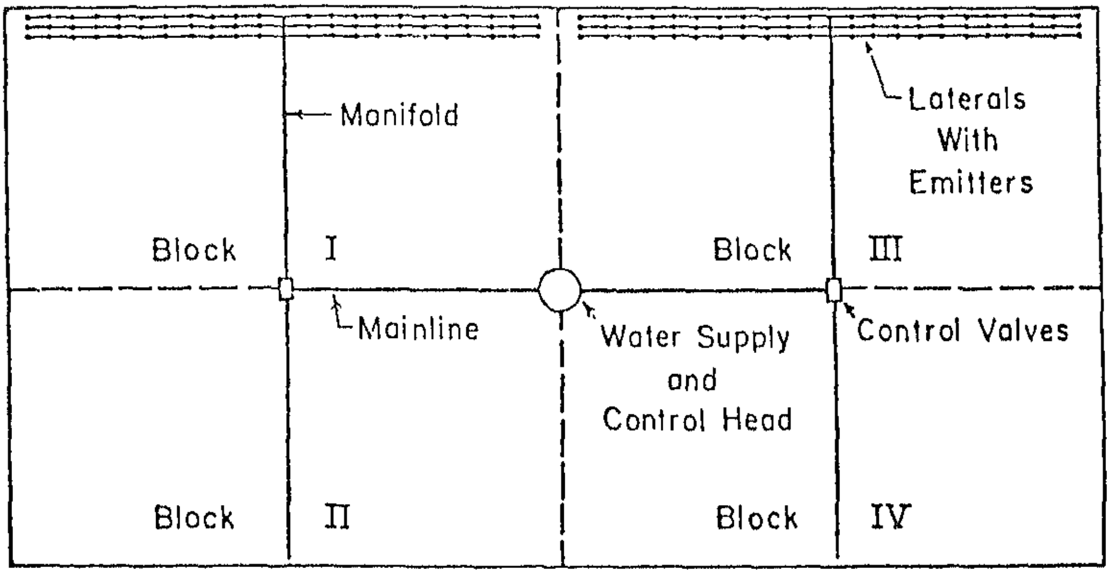

Figure B-11. Typical two station split flow layout for trickle irrigation system with Block I and III, or II and IV operating simultaneously.

which appears to have the greatest head differential for evaluation. Sketch the system layout and note in part 9 the general topography, manifold in operation and manifold where the discharge test will be conducted.

6. Record the system discharge rate (if the system is provided with a water meter) and the numbers of manifolds and blocks (or stations) in Part 10. The number of blocks is the total number of manifolds divided by the number of manifolds in operation at any one time.

7. For laterals having individual emitters, measure the discharge at two adjacent emission points (denoted as A and B in part 14) at each of four different tree or plant locations on each of the four selected test laterals. Collect the flow for a number of full minutes (1, 2, and 3, etc.) to obtain a volume between 100 and 250 ml for each emission point tested. Convert each reading to ml per minute before entering the data in part 14 on Figure B-10. To convert ml per minute to gallons per hour (gph), divide by 63.

These steps will produce eight pressure readings and 32 discharge volumes at 16 different plant locations for individual emission points used in wide-spaced crops with two or more emission points per plant.

For perforated hose or porous tubing, use the 3-ft trough and collect a discharge reading at each of the 16 locations described above. Since these are already averages from 2 or more outlets, only one reading is needed at each location.

For relatively wide-spaced crops such as grapes where one single outlet emitter may serve one or more plants, collect a discharge reading at each of the 16 locations described above. Since the plants are only served by a single emission point, only one reading should be made at each location.

8. Measure and record in part 15 the water pressures at the inlet
d downstream ends of each lateral tested in part 14 under normal
tion. On the inlet end, this may require disconnecting the lateral
stalling the pressure gauge, and reconnecting the hose before
pressure. Some systems are equipped with tire valve stems
and pressure can be read with the use of portable
wnstream end, the pressure can be read after connecting
e the simplest way possible.

centage of the soil that is wetted at one of the
test lateral and record in part 16. It is best
different relative location on each lateral. Use
or shovel--whichever seems to work best--for
the wetted zone in a horizontal plane about 6 to
il surface around each tree. Determine the
ividing the wetted area by the total surface area
e.

10. If an interval of several days between irrigations is being used, check the soil moisture deficit, S_{md}, in the wetted volume near a few representative trees in the next block to be irrigated and record it in part 17. This is difficult and requires averaging samples taken from several positions around each tree.

11. Determine the minimum lateral inlet pressure, MLIP, along each of the operating manifolds and record in part 18. For level or uphill manifolds, the MLIP will be at the far end of the manifold. For downhill manifolds it is often about two-thirds down the manifold. For manifolds on undulating terrain it is usually on a knoll or high point. When evaluating a system with two or more operating stations, the MLIP on each manifold should be determined. This will require cycling the system.

12. Determine the discharge correction factor, DCF, to adjust the average emission point discharges for the tested manifold. This adjustment is needed if the tested manifold happened to be operating with a higher or lower MLIP than the system average MLIP. If the emitter discharge exponent, x, is known, use the second formula presented in part 19.

13. Determine the average and adjusted average emission point discharges according to the equations in parts 11 and 12 of Figure B-10.

Utilization of field data

In trickle irrigation all the system flow is delivered to individual trees, vines, shrubs, or other plants. Essentially, there is no opportunity for loss of water except at the tree or plant locations. Therefore, uniformity of emission is of primary concern, assuming the crop is uniform. Locations of individual emission points, or the tree locations when several emitters are closely spaced, can be thought of in much the same manner as the container positions in tests of sprinkler performance.

Average application depth. The average dept
the wetted area, D_{aw}, is useful for es
from:

$$D'_{aw} = \frac{1.604\ e\ q'_a\ T_a}{A_w}$$

in which

D'_{aw} is the average depth applied pe

q'_a is the adjusted average emission point discharge of the system for part 12 Fig. B-10 (gph)

e is the number of emission points per tree

T_a is the application time per irrigation (hrs)

A_w is area wetted per tree or plant from part 16 (ft^2)

$$1.604 = \frac{gal}{hr} \times hrs \times \frac{ft^3}{7.48\ gal} \times \frac{12\ in}{ft} \times \frac{1}{ft^2}$$

The average depth applied per irrigation to the total cropped area can be found by substituting the plant spacing, $S_p \times S_r$, for the wetted area, A_w, in eq. B-1. Therefore:

$$D'_a = \frac{1.604\ e\ q'_a\ T_a}{S_p \times S_r} \qquad \text{(eq. B-2)}$$

in which

D'_a is the average depth applied per irrigation to the total cropped area (in)

S_p and S_r are plant and row spacing, ft.

Volume per day. The average volume of water applied per day for each tree or plant is:

$$G' = \frac{e\ q'_a\ T_a}{F_i} \qquad \text{(eq. B-3)}$$

in which

G' is the average volume of water applied per plant per day (gal/day)

F_i is the irrigation interval (days)

Emission Uniformity. The actual field emission uniformity, EU', is needed to determine the system operating efficiency and for estimating gross water application requirements. The EU' is a function of the emission uniformity in the tested area and the pressure variations throughout the entire system. Where the emitter discharge test data is from the area served by a single manifold:

$$EU'_m = 100\ q'_n/q'_a \qquad \text{(eq. B-4)}$$

in which

EU'_m is the field emission uniformity of the manifold area tested (percent)

q'_n and q'_a are the system low quarter and overall average emitter discharges, taken from Figure B-10, part 12 (gph).

Some trickle irrigation systems are fitted with pressure compensating emitters or have pressure or flow) regulation at the inlet to each lateral. Some systems are only provided with a means for pressure control or regulation at the inlets to the manifolds, others are provided with regulators at each lateral. If the manifold inlet pressures vary more than a few percent (due to design and/or management), the overall EU' (of the system) will be lower than EU'_m (of the tested manifold). An estimate of this efficiency reduction factor (ERF) can be computed from the minimum lateral inlet pressure along each manifold throughout the system by:

$$ERF = \frac{\text{average MLIP} + (1.5 \text{ minimum MLIP})}{2.5 \text{ (average MLIP)}} \qquad \text{(eq. B-5a)}$$

in which

ERF is the efficiency reduction factor

MLIP is the minimum lateral inlet pressure along a manifold (psi)

Average MLIP is the average of the individual MLIP along each manifold (psi)

Minimum MLIP is the lowest lateral inlet pressure in the system (psi)

A more precise method for estimating the ERF can be made by:

$$ERF = \left(\frac{\text{minimum MLIP}}{\text{average MLIP}} \right)^x \qquad \text{(eq. B-5b)}$$

x is the emitter discharge exponent

In cases where there are relatively small pressure variations and x = 0.5, the two methods for computing ERF give essentially equal results;

however, for pressure variations greater than 0.2 h_a or x values higher than 0.6 or lower than 0.4, the differences could be significant. Note - h_a is the average emitter pressure head.

The value of x can be estimated from field data as follows:

Step 1 Determine the average discharge and pressure of a group of at least 6 emitters along a lateral where the operating pressure is uniform.

Step 2 Reduce the operating pressure by adjusting the lateral inlet valve and again determine the average discharge and pressure of the same group of emitters.

Step 3 Determine x by Equation B-6 using the average discharge and pressure head values found in Steps 1 and 2.

$$X = \frac{\log\left(\frac{q_1}{q_2}\right)}{\log\left(\frac{h_1}{h_2}\right)} \qquad \text{(eq. B-6)}$$

Where

x = Emitter discharge exponent

q_1 = Average discharge of a group of emitters at pressure, h_1

q_2 = Average discharge of the same group of emitters at pressure, h_2

Step 4 Repeat steps 1, 2, and 3 at two other locations and average the x values for the three tests.

The ERF is approximately equal to the ratio between the average emission point discharge in the area served by the manifold with the minimum MLIP and the average emission point discharge for the system. Therefore, the system EU' can be approximated by:

$$EU' = (ERF)(EU'_m) \qquad \text{(eq. B-7)}$$

General criteria for EU' values for systems which have been in operation for one or more seasons are: greater than 90% excellent; between 80% and 90%, good; 70 to 80% fair; and less than 70% poor.

application required. Since trickle irrigation wets only a small
the soil volume, the S_{md} must be replaced frequently. It is
icult to estimate S_{md} because some regions of the wetted
oot zone often remain near field capacity even when the
irrigation is several days. For this reason, S_{md} must
a weather data or information derived from evaporation
stimates are subject to error and since there is no

practical way to check for slight underirrigation, some margin for safety should be allowed. As a general rule, the minimum gross depth of application, I_g, should be equal to (or slightly greater than) the values obtained by eq. B-8.

A bulbous tipped probe can be used to determine the area of the wetted bulb. If the wetted bulb increases over a series of irrigations, too much water is being applied. If the wetted bulb is decreasing in size, then there is underirrigation.

The gross depth per irrigation, I_g, should include sufficient water to compensate for the system uniformity and allow for unavoidable losses of the required leaching water. (Unavoidable losses can be used to satisfy leaching requirements or vice versa) To minimize the gross depth, systems should be well designed, accurately scheduled and carefully maintained. Where the unavoidable water losses are greater than the leaching water required, $T_r > 1/(1.0 - LR_t)$ or $LR_t < 0.1$:

$$I_g = \frac{I_n \quad T_r}{EU/100} \qquad \text{(eq. B-8)}$$

and where $T_r > 1/(1.0-LR_t)$ and $LR_t < 0.1$:

$$I_g = \frac{I_n}{EU/100\ (1.0 - LR_t)}$$

in which

however, for pressure variations greater than 0.2 h_a or x values higher than 0.6 or lower than 0.4, the differences could be significant. Note - h_a is the average emitter pressure head.

The value of x can be estimated from field data as follows:

Step 1 Determine the average discharge and pressure of a group of at least 6 emitters along a lateral where the operating pressure is uniform.

Step 2 Reduce the operating pressure by adjusting the lateral inlet valve and again determine the average discharge and pressure of the same group of emitters.

Step 3 Determine x by Equation B-6 using the average discharge and pressure head values found in Steps 1 and 2.

$$X = \frac{\log\left(\frac{q_1}{q_2}\right)}{\log\left(\frac{h_1}{h_2}\right)} \qquad \text{(eq. B-6)}$$

Where

x = Emitter discharge exponent

q_1 = Average discharge of a group of emitters at pressure, h_1

q_2 = Average discharge of the same group of emitters at pressure, h_2

Step 4 Repeat steps 1, 2, and 3 at two other locations and average the x values for the three tests.

The ERF is approximately equal to the ratio between the average emission point discharge in the area served by the manifold with the minimum MLIP and the average emission point discharge for the system. Therefore, the system EU' can be approximated by:

$$EU' = (ERF)(EU'_m) \qquad \text{(eq. B-7)}$$

General criteria for EU' values for systems which have been in operation for one or more seasons are: greater than 90% excellent; between 80% and 90%, good; 70 to 80% fair; and less than 70% poor.

Gross application required. Since trickle irrigation wets only a small portion of the soil volume, the S_{md} must be replaced frequently. It is always difficult to estimate S_{md} because some regions of the wetted portion of the root zone often remain near field capacity even when the interval between irrigation is several days. For this reason, S_{md} must be estimated from weather data or information derived from evaporation devices. Such estimates are subject to error and since there is no

practical way to check for slight underirrigation, some margin for safety should be allowed. As a general rule, the minimum gross depth of application, I_g, should be equal to (or slightly greater than) the values obtained by eq. B-8.

A bulbous tipped probe can be used to determine the area of the wetted bulb. If the wetted bulb increases over a series of irrigations, too much water is being applied. If the wetted bulb is decreasing in size, then there is underirrigation.

The gross depth per irrigation, I_g, should include sufficient water to compensate for the system uniformity and allow for unavoidable losses of the required leaching water. (Unavoidable losses can be used to satisfy leaching requirements or vice versa) To minimize the gross depth, systems should be well designed, accurately scheduled and carefully maintained. Where the unavoidable water losses are greater than the leaching water required, $T_r > 1/(1.0 - LR_t)$ or $LR_t < 0.1$:

$$I_g = \frac{I_n \quad T_r}{EU/100} \qquad \text{(eq. B-8)}$$

and where $T_r > 1/(1.0-LR_t)$ and $LR_t < 0.1$:

$$I_g = \frac{I_n}{EU/100\ (1.0 - LR_t)}$$

in which

I_g is the gross depth per irrigation, inches

T_r is the peak use period transpiration ratio

EU is the emission uniformity, percentage

LR_t is the leaching requirment under trickle irrigation, ratio - for

I_n is the net depth to be applied per irrigation, in

The T_r is the <u>ratio</u> of the depth of water applied to the area where T_d is exactly satisfied <u>to</u> the depth of water transpired. It represents the extra water which must be applied, even during peak use period, to offset unavoidable deep percolation losses. These losses are due to excess vertical water movement below the active root zone which is unavoidable in porous and shallow soils when sufficient lateral wetting is achieved. With efficient irrigation scheduling and for design purposes, use the following peak use period T_r values:

i) T_r = 1.00 for deep (greater than 5 ft) rooted crops on all soils except very porous gravely soils; medium (2.5 to 5 ft) rooted crops on fine and medium textured soils; and shallow rooted (less than 2.5 ft) on fine textured soils.

ii) T_r = 1.05 for deep rooted crops on gravely soils; medium rooted crops on coarse textured (sandy) soils; and shallow rooted crops on medium textured soils.

iii) T_r = 1.10 for medium rooted crops on gravely soils; or shallow rooted crops on coarse textured soils.

T_d in the above discussion is the peak month average daily transpiration rate of a crop under trickle irrigation, in/day.

When estimating I_g by eq. B-8 for managing (scheduling) irrigations let EU be the field EU' and estimate the net depth or irrigation to apply; I_n, as follows:

i) First estimate the depth of water which could have been consumed by a full canopy crop since the previous irrigation, I_n'. This can be done using standard techniques based on weather data or pan evaporation data.

ii) Next, subtract the depth of effective rainfall since the last irrigation, R_e'

iii) Then calculate I_n by:

$$I_n = (I_n' - R_e')[\frac{P_s}{100} + 0.15\ (1.0 - \frac{P_s}{100})] \qquad \text{(eq. B-9)}$$

P_s is the ground area shaded by the crop canopies at midday as a percent of the total area, percentage

Using I_g (computed by eq. B-8), the average daily gross volume of water required per plant per day, G, can be computed by eq. B-10. The average volumn of water actually being applied each day is computed by eq. B-3. If G G' the field is being overirrigated and if G > G', it is underirrigated. This can be verified with the use of a neutron probe or similar equipment. The gross volume of water required per plant per day, G, is useful for selecting the design emitter flow rate:

$$G = 0.623\ S_p\ S_r\ I_g/F_i \qquad \text{(eq. B-10)}$$

in which G is the gross water required per plant per day, gal/day.

S_p and S_r are the plant and row spacings, ft

I_g is the gross depth per irrigation, in

F_i is the irrigation interval (frequency), days

Application Efficiencies

A concept called potential application efficiency (of the low quarter), PE_{lq}, is useful for estimating how well a system can perform. It is a function of the peak use transpiration ratio, T_r, the leaching requirement, LR_t and EU'. When the unavoidable water losses are greater than the leaching water requirements., $T_r > 1/(1.0 - LR_t)$:

$$PE_{lq} = \frac{EU'}{T_r\ (1.0 - LR_t)} \qquad \text{(eq. B-11a)}$$

and where $T_r < 1/(1.0 - LR_t)$:

$$PE_{lq} = EU' \qquad \text{(eq. B-11b)}$$

The values for T_r are given in conjunction with eq. B-8 and LR_t by eq. B-12.

Leaching requirement, LR_t. In arid regions where salinity is a major importance, most of the natural precipitation is accounted for in R_e, W_a, nonbeneficial consumptive use, and/or runoff. There is usually very little additional natural precipitation, D_{rw}, that can add to deep percolation and consequently help satisfy the leaching requirements. Furthermore, since only a portion of the soil area is wetted and needs leaching under trickle irrigation, the effective additional precipitation is reduced to $(P_w/100)\ D_{rw}$; therefore, it can almost always be neglected. P_w is the average horizontal area wetted in the top part (6 to 12 in) of the crop root zone as a percentage of the total crop area.

Calculating the leaching requirement for trickle irrigation, LR_t is greatly simplified by neglecting $(P_w/100)D_{rw}$ and

$$LR_t = \frac{L_n}{T} = \frac{L_N}{T} = \frac{EC_w}{EC}$$

I_n and I_N are the net per irrigation application and net annual irrigation depths to meet consumptive use requirements, respectively in, EC_w is the electrical conductivity of the irrigation water, mmhos/cm EC_{dw} is the electrical conductivity of the drainage (deep percolation) water, mmhos/cm

Equation B-12 is based on a steady state salt balance condition, or in popular terminology, "what goes in, must come out and nothing comes from in between." It is important to understand the meaning of the number calculated for LR_t. It represents the minimum amount of water (in terms of a fraction of applied water) that must pass through the root zone to control salt buildup. The actual LR_t, however, is that amount of leaching water necessary to control salts in the root zone and this can only be determined by monitoring the soil salinity which is then related to field water management.

In a trickle irrigation system, there are no field boundary effects or pressure variations along the manifold tested which are not taken into account in the field estimate of EU'. Therefore, the estimated PE_{1q} is an overall value for the field except for possible minor water losses due to leaks, draining of lines, and flushing (unless leaks are excessive), with the system EU' (see eq. B-7).

The system PE_{1q} may be low because the manifold inlet pressures are not properly set and ERF (see eq. B-5) is low. In such cases, the manifold inlet pressures should be adjusted to increase the pressure uniformity and consequently ERF. When there is overirrigation, the actual application efficiency of the low quarter, E_{1q} will be less than PE_{1q}. In such cases the E_{1q} can be estimated by:

$$E_{1q} = \frac{100\ G}{G'} \qquad \text{(eq. B-13)}$$

when there is underirrigation and G' G then E_{1q} will approach the system EU'. In such cases the LR_t and/or the T_r will not be satisfied. This may cause excessive salt buildup in the least interest areas and/or a reduced volume of wetted soil.

APPENDIX C - DESIGN AIDS

Contents

Table C-1. Conversion Factors

Length

1 millimeter	=	0.03937 inch	1 mile	=	5,280 feet
1 centimeter	=	0.3937 inch		=	1.60935 kilometers
1 meter	=	39.37 inches	1 rod	=	16.5 feet
	=	3.2980 feet	1 chain	=	100 links or 66 feet
1 kilometer	=	3,280.8 feet	1 link	=	7.92 inches

Area

1 acre	=	43,560 square feet
1 hectare	=	2.471 acres

Volume

1 acre-inch	=	27,152.4 gallons	1 cubic foot	=	7.48 U.S. gallons
1 acre-foot	=	325,828.8 gallons		=	1728 cubic inches
	=	43,560 cubic feet		=	28.316 litres
	=	12 acre-inches	1 litre	=	0.2642 U.S. gallons
1 U.S. gallon	=	231.0 cubic inches	1 cubic meter	=	264.0 U.S. gallons
	=	0.1337 cubic foot			
	=	3.7853 litres			

Rate of Flow

1 cfm	=	7.48 gpm
1 acre-inch/hr	=	452.57 gpm
1 cfs	=	448.83 gpm
	=	7.48 gallons per second
1 gpm	=	0.0023 cubic feet per second
	=	1440 gallons per day

Weights

1 U.S. gallon	=	8.326 pounds
1 cubic foot of water	=	62.428 pounds

Temperature

Degrees C	=	$5/9\ (F - 32^{o})$
Degrees F	=	$9/5\ C + 32^{o}$

Pressure

1 atmosphere	=	
	=	
1 foot of water	=	0.433 psi
	=	0.883 inches of Mercury (Hg)
1 psi	=	2.31 feet of water
1 inch of Mercury (Hg)	=	1.133 feet of water

Mechanical and Electrical

1 horsepower	=	745.7 watts
	=	33,000 foot pounds per minute
1 kilowatt	=	1,000 watts
	=	1.341 horsepower

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES MANUFACTURED OF PVC OR ABS COMPOUNDS STANDARD DIMENSION RATIO - SDR = 21 1/

For IPS Pipe

Friction Head Loss in Feet per Hundred Feet

Q Gallons per min.	1-inch 1.189 ID	1¼-inch 1.502 ID	1½-inch 1.720 ID	2-inch 2.149 ID	2½-inch 2.601 ID	3-inch 3.166 ID	3½-inch 3.620 ID	Q Gallons per min.
2	.15	.04	.02					2
4	.54	.17	.09	.03	.01			4
6	1.15	.37	.19	.06	.02			6
8	1.97	.63	.32	.11	.04	.01		8
10	2.98	.95	.49	.16	.06	.02	.01	10
15	6.32	2.03	1.04	.35	.14	.05	.02	15
20	10.79	3.46	1.78	.60	.23	.09	.04	20
25	16.30	5.22	2.70	.91	.36	.13	.07	25
30	22.86	7.32	3.78	1.27	.50	.19	.10	30
35		9.75	5.03	1.70	.67	.25	.13	35
40		12.46	6.46	2.18	.86	.32	.17	40
45		15.51	8.02	2.71	1.07	.40	.21	45
50		18.87	9.75	3.30	1.30	.49	.25	50
55		22.48	11.64	3.94	1.54	.59	.30	55
60			13.64	4 62	1.81	.69	.36	60
65			15.85	5.36	2.10	.80	.41	65
70			18.19	6.14	2.42	.92	.47	70
75			20.65	6.99	2.75	1.06	.55	75
80			23.28	7.86	3.10	1.19	.62	80
85				8.81	3.47	1.33	.69	85
90				9.79	3.85	1.48	.77	90
95				10.82	4.25	1.64	.85	95
100				11.89	4.69	1.80	.93	100
110				14.21	5.59	2.14	1.11	110
120				16.69	6.56	2.52	1.31	120
130				19.35	7.63	2.92	1.53	130
140				22.21	8.73	3.36	1.75	140
150					9.94	3.82	1.99	150
160					11.20	4.29	2.24	160
170					12.51	4.80	2.50	170
180					13.90	5.35	2.79	180
190					15.39	5.92	3.08	190
200					16.91	6.50	3.38	200
220					20.19	7.77	4.04	220
240					23.73	9.12	4.76	240
260						10.57	5.51	260
280						12.11	6.32	280
300						13.78	7.18	300
320						15.52	8.10	320
340						17.37	9.07	340
360						19.27	10.08	360
380						21.33	11.13	380
400						23.45	12.22	400
420							13.40	420
440							14.59	440
460							15.86	460
480							17.15	480
500							18.50	500

Table based on Hazen-Williams equation - C_1 = 150

1/ To find friction head loss in PVC or ABS pipe having a standard dimension ratio other than 21, the values in the table should be multiplied by the appropriate conversion factor shown below:

SDR No.	Conversion Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Velocity of values below dotted line exceed 5 fps

Table C-2

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENSION RATIO - SDR = 21 1/

For IPS Pipe

Friction Head Loss in Feet per Hundred Feet

Q Gallons per min.	4-inch 4.072 ID	5-inch 5.033 ID	6-inch 5.993 ID	8-inch 7.805 ID	10-inch 9.728 ID	12-inch 11.538 ID	Q Gallons per min.
15	.01						15
20	.02						20
25	.04	.01					25
30	.05	.02					30
35	.07	.02	.01				35
40	.09	.03	.01				40
45	.12	.04	.01				45
50	.14	.05	.02				50
55	.17	.06	.02				55
60	.20	.07	.03				60
65	.23	.08	.03	.01			65
70	.27	.09	.04	.01			70
75	.31	.11	.04	.01			75
80	.35	.12	.05	.01			80
85	.39	.14	.05	.01			85
90	.43	.15	.06	.01			90
95	.48	.17	.07	.02			95
100	.52	.19	.07	.02			100
110	.63	.22	.09	.02			110
120	.74	.26	.10	.03	.01		120
130	.85	.30	.12	.03	.01		130
140	.98	.35	.14	.04	.01		140
150	1.11	.40	.16	.05	.01		150
160	1.26	.44	.19	.05	.01		160
170	1.41	.49	.21	.06	.02		170
180	1.57	.55	.24	.07	.02	.01	180
190	1.73	.61	.26	.07	.02	.01	190
200	1.90	.67	.29	.08	.02	.01	200
220	2.28	.81	.34	.09	.03	.01	220
240	2.67	.95	.40	.10	.03	.01	240
260	3.10	1.10	.46	.12	.04	.02	260
280	3.56	1.26	.54	.14	.05	.02	280
300	4.04	1.43	.61	.17	.05	.02	
320	4.56	1.62	.69	.19	.06		
340	5.10	1.82	.77	.21	.07		
360	5.67	2.02	86	.24	.08		
380	6.26	2.22	.95	.26	.09		
400	6.90	2.45	1.04	.28	.10		
420	7.55	2.69	1.14	.31	.10		
440	8.23	2.92	1.25	.34	.11		
460	8.94	3.18	1.35	.37	.12		
480	9.67	3.44	1.46	.41	.14		
500	10.42	3.70	1.58	.43	.15		
550	12.44	4.42	1.89	.52	.18		
600	14.61	5.21	2.22	.61	.21		

SDR No.	Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Table C-2

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENSION RATIO - SDR = 21 1/

For IPS Pipe

Q Gallons per min.	4-inch 4.072 ID	5-inch 5.033 ID	6-inch 5.993 ID	8-inch 7.805 ID	10-inch 9.728 ID	12-inch 11.538 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet						
600	14.61	5.21	2.22	.61	.21	.09	600
650	16.94	6.04	2.58	.71	.24	.10	650
700	19.45	6.92	2.96	.81	.28	.12	700
750	22.08	7.87	3.36	.93	.32	.14	750
800		8.88	3.78	1.04	.36	.16	800
850		9.93	4.24	1.17	.40	.17	850
900		11.05	4.71	1.30	.44	.19	900
950		12.18	5.21	1.44	.49	.21	950
1000		13.40	5.73	1.58	.54	.23	1000
1050		14.67	6.27	1.73	.59	.26	1050
1100		16.00	6.83	1.88	.65	.28	1100
1150		17.39	7.41	2.05	.70	.30	1150
1200		18.80	8.02	2.21	.76	.33	1200
1250		20.27	8.66	2.39	.82	.35	1250
1300		21.78	9.32	2.57	.88	.37	1300
1350			9.99	2.76	.95	.40	1350
1400			10.66	2.95	1.01	.43	1400
1450			11.40	3.16	1.08	.47	1450
1500			12.13	3.35	1.15	.50	1500
1600			13.68	3.78	1.30	.56	1600
1700			15.29	4.23	1.45	.62	1700
1800			16.99	4.70	1.62	.70	1800
1900			18.81	5.20	1.79	.77	1900
2000			20.66	5.72	1.97	.84	2000
2100			22.61	6.26	2.15	.93	2100
2200			24.67	6.83	2.34	1.01	2200
2300				7.42	2.55	1.10	2300
2400				8.02	2.76	1.19	2400
2500				8.67	2.97	1.29	2500
2600	SDR No.	Factor		9.31	3.20	1.39	2600
2700	13.5	1.35		9.98	3.43	1.49	2700
2800	17	1.13		10.67	3.67	1.59	2800
2900	21	1.00		11.39	3.92	1.69	2900
3000	26	.91		12.10	4.17	1.81	3000
3100	32.5	.84		12.89	4.43	1.92	3100
3200	41	.785		13.66	4.71	2.04	3200
3300	51	.75		14.46	4.97	2.15	3300
3400				15.29	5.27	2.28	3400
3500				16.11	5.56	2.41	3500
3600				16.99	5.85	2.53	3600
3700				17.89	6.17	2.67	3700
3800				18.76	6.47	2.80	3800
3900				19.69	6.79	2.94	3900
4000				20.67	7.11	3.08	4000

Table C-3

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENSION RATIO - SDR = 21 1/

For PIP Pipe

Friction Head Loss in Feet per Hundred Feet

Table based on Hazen-Williams equation - C_1 = 150.

Q Gallons per min.	4-inch 3.736 ID	6-inch 5.556 ID	8-inch 7.382 ID	10-inch 9.228 ID	12-inch 11.074 ID	Q Gallons per min.
15	.02					15
20	.04					20
25	.06					25
30	.09	.01				30
35	.12	.02				35
40	.15	.02				40
45	.18	.03				45
50	.22	.03				50
55	.27	.04				55
60	.31	.05				60
65	.36	.05	.01			65
70	.42	.06	.02			70
75	.47	.07	.02			75
80	.53	.08	.02			80
85	.60	.09	.02			85
90	.66	.10	.02			90
95	.73	.11	.03			95
100	.80	.12	.03			100
110	.96	.14	.03			110
120	1.13	.16	.04	.01		120
130	1.31	.19	.05	.02		130
140	1.50	.22	.05	.02		140
150	1.70	.25	.06	.02		150
160	1.92	.28	.07	.02		160
170	2.15	.31	.08	.03		170
180	2.39	.35	.09	.03		180
190	2.64	.38	.10	.03		190
200	2.90	.42	.11	.04	.01	200
220	3.46	.50	.13	.04	.02	220
240	4.07	.59	.15	.05	.02	240
260	4.72	.68	.17	.06	.02	260
280	5.41	.78	.20	.07	.03	280
300	6.15	.89	.22	.08	.03	
320	6.93	1.00	.25	.08	.03	
340	7.76	1.12	.28	.09	.04	
360	8.62	1.25	.31	.11	.04	
380	9.53	1.38	.35	.12	.05	
400	10.48	1.52	.38	.13	.05	
420	11.47	1.66	.42	.14	.06	
440	12.50	1.81	.45	.15	.06	
460	13.58	1.96	.49	.17	.07	
480	14.69	2.13	.53	.18	.07	
500	15.84	2.29	.57	.19	.08	
550	18.90	2.74	.69	.23	.10	
600	22.21	3.21	.81	.27	.11	

1/ To find friction head loss in PVC or ABS pipe having a standard dimension ratio other than 21, the values in the table should be multiplied by the appropriate conversion factor shown below:

SDR No.	Conversion Factor
13.5	1.34
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Velocity of values below dotted line exceed 5 fps

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Table C-3

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENSION RATIO - SDR = 21 1/

For PIP Pipe

Q Gallons per min.	4-inch 3.736 ID	6-inch 5.556 ID	8-inch 7.382 ID	10-inch 9.228 ID	12-inch 11.074 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet					
650		3.75	.93	.31	.13	650
700		4.28	1.07	.36	.15	700
750		4.86	1.22	.41	.17	750
800		5.47	1.37	.46	.19	800
850		6.13	1.53	.52	.21	850
900		6.81	1.71	.58	.24	900
950		7.53	1.89	.64	.26	950
1000		8.28	2.07	.70	.29	1000
1050		9.06	2.27	.77	.31	1050
1100		9.87	2.47	.83	.34	1100
1150		10.72	2.69	.91	.37	1150
1200		11.60	2.91	.98	.40	1200
1250		12.51	3.13	1.06	.43	1250
1300		13.45	3.37	1.14	.47	1300
1350		14.43	3.61	1.22	.50	1350
1400		15.43	3.87	1.30	.54	1400
1450		16.47	4.13	1.39	.57	1450
1500		17.54	4.39	1.48	.61	1500
1600		19.76	4.95	1.67	.69	1600
1700		22.11	5.54	1.87	.77	1700
1800		24.58	6.16	2.08	.85	1800
1900			6.81	2.29	.94	1900
2000			7.49	2.52	1.04	2000
2100			8.19	2.76	1.14	2100
2200			8.93	3.01	1.24	2200
2300			9.70	3.27	1.35	2300
2400			10.49	3.54	1.46	2400
2500			11.32	3.82	1.57	2500
2600			12.17	4.10	1.69	2600
2700			13.05	4.40	1.81	2700
2800			13.96	4.71	1.94	2800
2900			14.90	5.02	2.07	2900
3000			15.86	5.35	2.20	3000
0			16.85	5.68	2.34	3100
0			17.88	6.03	2.48	3200
0			18.92	6.38	2.62	3300
0			20.00	6.74	2.77	3400
0			21.10	7.11	2.93	3500
			22.23	7.50	3.08	3600
			23.39	7.89	3.24	3700
			24.57	8.28	3.41	3800
				8.69	3.58	3900
				9.11	3.75	4000

SDR No.	Factor
13.5	1.34
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Table C-4

FRICTION LOSS CHARACTERISTICS
PVC CLASS 315 IPS PLASTIC PIPE

(1120, 1220) SDR 13.5 C = 150
PSI LOSS PER 100 FEET OF PIPE (PSI/100 FT)

Sizes ½" thru 3½"
Flow GPM 1 thru 600

SIZE	0.50	0.75	1.00	1.25	1.50	2.00	2.50	3.00	3.50	SIZE
OD	0.840	1.050	1.315	1.660	1.900	2.375	2.875	3.500	4.000	OD
ID	0.716	0.894	1.121	1.414	1.618	2.023	2.449	2.982	3.408	ID
WALL THK	0.062	0.078	0.097	0.123	0.141	0.176	0.213	0.259	0.296	WALL THK

Flow G.P.M.	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Flow G.P.M.
1	0.79	0.22	0.51	0.07	0.32	0.02	0.20	0.01	0.15	0.00									1
2	1.59	0.78	1.02	0.27	0.64	0.09	0.40	0.03	0.31	0.01	0.19	0.00							2
3	2.38	1.65	1.53	0.56	0.97	0.19	0.61	0.06	0.46	0.03	0.29	0.01	0.20	0.00					3
4	3.18	2.82	2.04	0.96	1.29	0.32	0.81	0.10	0.62	0.05	0.39	0.02	0.27	0.01					4
5	3.97	4.26	2.55	1.45	1.62	0.48	1.02	0.16	0.77	0.08	0.49	0.03	0.34	0.01	0.22	0.00			5
6	4.77	5.97	3.06	2.03	1.94	0.67	1.22	0.22	0.93	0.11	0.59	0.04	0.40	0.02	0.27	0.01			6
7	5.67	7.95	3.57	2.70	2.27	0.90	1.42	0.29	1.09	0.15	0.69	0.05	0.47	0.02	0.32	0.01	0.24	0.00	7
8	6.36	10.18	4.08	3.45	2.59	1.15	1.63	0.37	1.24	0.19	0.79	0.06	0.54	0.03	0.36	0.01	0.28	0.01	8
9	7.16	12.66	4.59	4.30	2.92	1.43	1.83	0.46	1.40	0.24	0.89	0.08	0.61	0.03	0.41	0.01	0.31	0.01	9
10	7.95	15.38	5.10	5.22	3.24	1.74	2.04	0.56	1.55	0.29	0.99	0.10	0.68	0.04	0.45	0.01	0.35	0.01	10
11	8.75	18.35	5.61	6.23	3.57	2.07	2.24	0.67	1.71	0.35	1.09	0.12	0.74	0.05	0.50	0.02	0.38	0.01	11
12	9.55	21.56	6.12	7.32	3.89	2.43	2.44	0.79	1.87	0.41	1.19	0.14	0.81	0.05	0.55	0.02	0.42	0.01	12
14	11.14	28.69	7.14	9.74	4.54	3.24	2.85	1.05	2.18	0.54	1.39	0.18	0.95	0.07	0.64	0.03	0.49	0.01	14
16	12.73	36.74	8.16	12.47	5.19	4.15	3.26	1.34	2.49	0.70	1.59	0.23	1.08	0.09	0.73	0.04	0.56	0.02	16
18	14.32	45.69	9.18	15.51	5.84	5.16	3.67	1.67	2.80	0.87	1.79	0.29	1.22	0.12	0.82	0.04	0.63	0.02	18
20	15.91	55.54	10.20	18.86	6.49	6.27	4.08	2.03	3.11	1.05	1.99	0.35	1.36	0.14	0.91	0.05	0.70	0.03	20
22	17.50	66.26	11.23	22.50	7.14	7.48	4.48	2.42	3.42	1.25	2.19	0.42	1.49	0.17	1.00	0.06	0.77	0.03	22
24	19.10	77.84	12.25	26.40	7.79	8.79	4.89	2.84	3.74	1.47	2.39	0.50	1.63	0.20	1.10	0.08	0.84	0.04	24
26			13.27	30.65	8.44	10.19	5.30	3.29	4.05	1.71	2.59	0.58	1.76	0.23	1.19	0.09	0.91	0.05	26
28			14.29	35.16	9.09	11.69	5.71	3.78	4.36	1.96	2.79	0.66	1.90	0.26	1.28	0.10	0.98	0.05	28
30			15.31	39.95	9.74	13.29	6.12	4.29	4.67	2.23	2.99	0.75	2.04	0.30	1.37	0.11	1.05	0.06	30
35			17.86	53.15	11.36	17.68	7.14	5.71	5.45	2.96	3.48	1.00	2.38	0.39	1.60	0.15	1.22	0.08	35
40					12.98	22.64	8.16	7.31	6.23	3.80	3.98	1.28	2.72	0.51	1.83	0.19	1.40	0.10	40
45					14.61	28.15	9.18	9.10	7.01	4.72	4.48	1.59	3.06	0.63	2.06	0.24	1.58	0.13	45
50					16.23	34.27	10.20	11.06	7.79	5.74	4.98	1.94	3.40	0.76	2.29	0.29	1.75	0.15	50
55					17.85	40.83	11.22	13.19	8.57	6.85	5.48	2.31	3.74	0.91	2.52	0.35	1.93	0.18	55
60					19.48	47.97	12.24	15.50	9.36	8.04	5.98	2.71	4.08	1.07	2.75	0.41	2.10	0.21	60
65							13.26	17.97	10.13	9.33	6.48	3.15	4.42	1.24	2.98	0.48	2.28	0.25	65
70							14.28	20.62	10.90	10.70	6.97	3.61	4.76	1.42	3.21	0.55	2.45	0.29	70
75							15.30	23.43	11.68	12.16	7.47	4.10	5.10	1.62	3.44	0.62	2.63	0.32	75
80							16.32	26.40	12.46	13.71	7.97	4.62	5.44	1.82	3.67	0.70	2.81	0.37	80
85							17.34	29.54	13.24	15.33	8.47	5.17	5.78	2.04	3.89	0.78	2.98	0.41	85
90							18.36	32.84	14.02	17.05	8.97	5.75	6.12	2.27	4.12	0.87	3.16	0.45	90
95							19.38	36.30	14.80	18.84	9.47	6.35	6.46	2.51	4.35	0.96	3.33	0.50	95
100									15.58	20.72	9.96	6.99	6.80	2.76	4.58	1.06	3.51	0.55	100
110									17.14	24.72	10.96	8.34	7.48	3.29	5.04	1.26	3.86	0.66	110
120									18.70	29.04	11.96	9.79	8.16	3.87	5.50	1.48	4.21	0.77	120
130											12.96	11.36	8.84	4.48	6.96	1.72	4.56	0.90	130
140											13.95	13.03	9.52	5.14	6.42	1.07	4.91	1.03	140
150											14.95	14.81	10.70	5.84	6.88	2.24	5.26	1.17	150
160											15.95	16.69	10.88	6.59	7.34	2.53	5.62	1.32	160
170											16.94	18.67	11.56	7.37	7.79	2.83	5.97	1.48	170
180											17.94	20.75	12.24	8.19	8.25	3.14	6.32	1.64	180
190											18.94	22.94	12.92	9.05	8.71	3.47	6.67	1.81	190
200											19.93	25.23	13.60	9.95	9.17	3.82	7.02	1.99	200
225													15.30	12.38	10.32	4.75	7.90	2.49	225
250													17.00	15.05	11.47	5.77	8.78	3.01	250
275													18.70	17.95	12.61	6.89	9.66	3.60	275
300															[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
325																			
350																			
375																			
400																			
425																			
450																			
475																			
500																			
550																			
600																			

Velocity below dotted l

Table C-5

FRICTION LOSS CHARACTERISTICS
PVC SCHEDULE 40 IPS PLASTIC PIPE

(1120, 1220) C = 150
PSI LOSS PER 100 FEET OF TUBE (PSI/100 FT)
Sizes ½" thru 3½"
Flow GPM 1 thru 600

SIZE	0.50	0.75	1.00	1.25	1.50	2.00	2.50	3.00	3.50	SIZE
OD	0.840	1.050	1.315	1.660	1.900	2.375	2.875	3.500	4.000	OD
ID	0.622	0.824	1.049	1.380	1.610	2.067	2.469	3.068	3.548	ID
WALL THK	0.109	0.113	0.133	0.140	0.145	0.154	0.203	0.216	0.226	WALL THK

Flow G.P.M.	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Flow G.P.M.
1	0.93	0.32	0.60	0.11	0.37	0.03	0.21	0.01	0.15	0.00									1
2	1.86	1.14	1.20	0.39	0.74	0.12	0.42	0.03	0.31	0.02	0.19	0.00							2
3	2.79	2.42	1.80	0.94	1.11	0.26	0.64	0.07	0.47	0.03	0.28	0.01	0.20	0.00					3
4	3.72	4.13	2.40	1.42	1.48	0.44	0.85	0.12	0.62	0.05	0.38	0.02	0.26	0.01					4
5	4.65	6.24	3.00	2.15	1.85	0.66	1.07	0.18	0.78	0.08	0.47	0.02	0.33	0.01	0.21	0.00			5
6	5.58	8.75	3.60	3.02	2.22	0.93	1.28	0.25	0.94	0.12	0.57	0.03	0.40	0.01	0.26	0.01			6
7	6.51	11.64	4.20	4.01	2.59	1.24	1.49	0.33	1.10	0.15	0.66	0.05	0.46	0.02	0.30	0.01			7
8	7.44	14.90	4.80	5.14	2.96	1.59	1.71	0.42	1.25	0.20	0.76	0.06	0.53	0.02	0.34	0.01	0.25	0.00	8
9	8.37	18.54	5.40	6.39	3.33	1.97	1.92	0.52	1.41	0.25	0.85	0.07	0.60	0.03	0.39	0.01	0.29	0.01	9
10	9.30	22.53	6.00	7.77	3.70	2.40	2.14	0.63	1.57	0.30	0.95	0.09	0.66	0.04	0.43	0.01	0.32	0.01	10
11	10.24	26.88	6.60	9.27	4.07	2.86	2.35	0.75	1.73	0.36	1.05	0.11	0.73	0.04	0.47	0.02	0.35	0.01	11
12	11.17	31.58	7.21	10.89	4.44	3.36	2.57	0.89	1.88	0.42	1.14	0.12	0.80	0.05	0.52	0.02	0.38	0.01	12
14	13.03	42.01	8.41	14.48	5.19	4.47	2.99	1.18	2.20	0.56	1.33	0.17	0.93	0.07	0.60	0.02	0.45	0.01	14
16	14.89	53.80	9.61	18.55	5.93	5.73	3.42	1.51	2.51	0.71	1.52	0.21	1.07	0.09	0.69	0.03	0.51	0.02	16
18	16.75	66.92	10.81	23.07	6.67	7.13	3.85	1.88	2.83	0.99	1.71	0.26	1.20	0.11	0.78	0.04	0.58	0.02	18
20	18.61	81.34	12.01	28.04	7.41	8.66	4.28	2.28	3.14	1.08	1.90	0.32	1.33	0.13	0.86	0.05	0.64	0.02	20
22			13.21	33.45	8.15	10.33	4.71	2.72	3.46	1.29	2.10	0.38	1.47	0.16	0.95	0.06	0.71	0.03	22
24			14.42	39.30	8.89	12.14	5.14	3.20	3.77	1.51	2.29	0.45	1.60	0.19	1.04	0.07	0.77	0.03	24
26			15.62	45.58	9.64	14.08	5.57	3.17	4.09	1.75	2.48	0.52	1.74	0.22	1.12	0.08	0.84	0.04	26
28			16.82	52.28	10.38	16.15	5.99	4.25	4.40	2.01	2.67	0.60	1.87	0.25	1.21	0.09	0.90	0.04	28
30			18.02	59.41	11.12	18.35	6.42	4.83	4.72	2.28	2.86	0.68	2.00	0.29	1.30	0.10	0.97	0.05	30
35					12.97	24.42	7.49	6.43	5.50	3.04	3.34	0.90	2.34	0.38	1.51	0.13	1.13	0.06	35
40					14.83	31.27	8.56	8.23	6.29	3.89	3.81	1.15	2.67	0.49	1.73	0.17	1.29	0.08	40
45					16.68	38.89	9.64	10.24	7.08	4.84	4.29	1.43	3.01	0.60	1.95	0.21	1.45	0.10	45
50					18.53	47.27	10.71	12.45	7.87	5.88	4.77	1.74	3.34	0.73	2.16	0.26	1.62	0.13	50
55							11.78	14.85	8.65	7.01	5.25	2.08	3.68	0.88	2.38	0.30	1.78	0.15	55
60							12.85	17.45	9.44	8.24	5.72	2.44	4.01	1.03	2.60	0.36	1.94	0.18	60
65							13.92	20.23	10.23	9.56	6.20	2.83	4.35	1.19	2.81	0.41	2.10	0.20	65
70							14.99	23.21	11.01	10.96	6.68	3.25	4.68	1.37	3.03	0.48	2.26	0.23	70
75							16.06	26.37	11.80	12.46	7.16	3.69	5.01	1.56	3.25	0.54	2.43	0.27	75
80							17.13	29.72	12.59	14.04	7.63	4.16	5.35	1.75	3.46	0.61	2.59	0.30	80
85							18.21	33.26	13.37	15.71	8.11	4.66	5.68	1.96	3.68	0.68	2.75	0.34	85
90							19.28	36.97	14.16	17.46	8.59	5.18	6.02	2.18	3.90	0.76	2.91	0.37	90
95									14.96	19.30	9.07	5.72	6.35	2.41	4.11	0.84	3.07	0.41	95
100									15.74	21.22	9.54	6.29	6.69	2.65	4.33	0.92	3.24	0.45	100
									17.31	25.32	10.50	7.51	7.36	3.16	4.76	1.10	3.56	0.54	110
									18.88	29.75	11.45	8.82	8.03	3.72	5.20	1.29	3.88	0.64	120
											12.41	10.23	8.70	4.31	5.63	1.50	4.21	0.74	130
											13.36	11.74	9.37	4.94	6.06	1.72	4.53	0.85	140
											14.32	13.33	10.03	5.62	6.50	1.95	4.86	0.96	150
											15.27	15.03	10.70	6.33	6.93	2.20	5.18	1.08	160
											16.23	16.81	11.37	7.08	7.36	2.46	5.50	1.21	170
											17.18	18.69	12.04	7.87	7.80	2.74	5.83	1.35	180
											18.14	20.66	12.71	8.70	8.23	3.02	6.15	1.40	190
											19.09	22.72	13.38	9.57	8.66	3.33	6.48	1.64	200
													15.05	11.90	9.75	4.14	7.29	2.04	225
													16.73	14.47	10.83	5.03	8.10	2.48	250
													18.40	17.26	11.92	6.00	8.91	2.96	275
															13.00	7.05	9.72	3.47	300
															14.08	8.17	10.53	4.03	325
															15.17	9.38	11.34	4.62	350
															16.25	10.65	12.15	5.25	375
															17.33	12.01	12.96	5.92	400
															18.42	13.43	13.77	6.62	425
															19.50	14.93	14.58	7.36	450
																	15.39	8.14	475
																	16.20	8.95	500
																	17.82	10.67	550
																	19.44	12.54	600

ocity below dotted line exceeds 5 fps

Table C-6

FRICTION LOSS CHARACTERISTICS
PVC SCHEDULE 40 IPS PLASTIC PIPE
(1120, 1220) C = 150
PSI LOSS PER 100 FEET OF TUBE (PSI/100 FT)

Sizes 4" thru 12"
Flow GPM 1 thru 600

SIZE	4.00	5.00	6.00	8.00	10.00	12.00	SIZE
OD	4.500	5.563	6.625	8.625	10.750	12.750	OD
ID	4.026	5.047	6.065	7.981	10.020	11.814	ID
WALL THK	0.237	0.258	0.280	0.322	0.365	0.406	WALL THK

Flow G.P.M.	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Flow G.P.M.
1													1
2													2
3													3
4													4
5													5
6													6
7													7
8													8
9													9
10													10
11													11
12	0.30	0.00											12
14	0.35	0.01											14
16	0.40	0.01											16
18	0.45	0.01											18
20	0.50	0.01											20
22	0.55	0.01	0.35	0.00									22
24	0.60	0.02	0.38	0.01									24
26	0.65	0.02	0.41	0.01									26
28	0.70	0.02	0.44	0.01									28
30	0.75	0.03	0.48	0.01									30
35	0.88	0.04	0.56	0.01	0.38	0.00							35
40	1.00	0.04	0.64	0.01	0.44	0.01							40
45	1.13	0.06	0.72	0.02	0.49	0.01							45
50	1.25	0.07	0.80	0.02	0.55	0.01							50
55	1.38	0.08	0.88	0.03	0.61	0.01							55
60	1.51	0.10	0.96	0.03	0.66	0.01							60
65	1.63	0.11	1.04	0.04	0.72	0.02							65
70	1.76	0.13	1.12	0.04	0.77	0.02	0.44	0.00					70
75	1.88	0.14	1.20	0.05	0.83	0.02	0.48	0.01					75
80	2.01	0.16	1.28	0.05	0.88	0.02	0.51	0.01					80
85	2.13	0.18	1.36	0.06	0.94	0.02	0.54	0.01					85
90	2.26	0.20	1.44	0.07	0.99	0.03	0.57	0.01					90
95	2.39	0.22	1.52	0.07	1.05	0.03	0.60	0.01					95
100	2.51	0.25	1.60	0.08	1.10	0.03	0.64	0.01					100
110	2.76	0.29	1.76	0.10	1.22	0.04	0.70	0.01					110
120	3.02	0.34	1.92	0.11	1.33	0.05	0.76	0.01					120
130	3.27	0.40	2.08	0.13	1.44	0.05	0.83	0.01	0.52	0.00			130
140	3.52	0.46	2.24	0.15	1.55	0.06	0.89	0.02	0.56	0.01			140
150	3.77	0.52	2.40	0.17	1.66	0.07	0.96	0.02	0.60	0.01			150
160	4.02	0.59	2.56	0.20	1.77	0.08	1.02	0.02	0.65	0.01			160
170	4.27	0.66	2.72	0.22	1.88	0.09	1.09	0.02	0.69	0.01			170
180	4.53	0.73	2.88	0.24	1.99	0.10	1.15	0.03	0.73	0.01			180
190	4.78	0.81	3.04	0.27	2.10	0.11	1.21	0.03	0.77	0.01			190
200	5.03	0.89	3.20	0.30	2.21	0.12	1.28	0.03	0.81	0.01	0.58	0.00	200
225	5.66	1.10	3.60	0.37	2.49	0.15	1.44	0.04	0.91	0.01	0.65	0.01	225
250	6.29	1.34	4.00	0.45	2.77	0.18	1.60	0.05	1.01	0.02	0.73	0.01	250
275	6.92	1.60	4.40	0.53	3.05	0.22	1.76	0.06	1.11	0.02	0.80	0.01	275
300	7.55	1.88	4.80	0.63	3.32	0.26	1.92	0.07	1.21	0.02	0.87	0.01	300
325	8.18	2.18	5.20	0.73	3.60	0.30	2.08	0.08	1.32	0.03	0.95	0.01	325
350	8.81	2.50	5.60	0.83	3.88	0.34	2.24	0.09	1.42	0.03	1.02	0.01	350
375	9.43	2.84	6.00	0.95	4.15	0.39	2.40	0.10	1.52	0.03	1.09	0.02	375
400	10.06	3.20	6.40	1.07	4.43	0.44	2.56	0.11	1.62	0.04	1.16	0.02	400
425	10.69	3.58	6.80	1.19	4.71	0.49	2.72	0.13	1.72	0.04	1.24	0.02	425
450	11.32	3.98	7.20	1.33	4.99	0.54	2.88	0.14	1.82	0.05	1.31	0.02	450
475	11.95	4.40	7.60	1.46	5.26	0.60	3.04	0.16	1.93	0.05	1.38	0.02	475
500	12.58	4.84	8.00	1.61	5.54	0.66	3.20	0.17	2.03	0.06	1.46	0.03	500
550	13.84	5.77	8.80	1.92	6.10	0.79	3.52	0.21	2.23	0.07	1.60	0.03	550
600	15.10	6.78	9.61	2.26	6.65	0.92	3.84	0.24	2.43	0.08	1.75	0.04	600

Velocity below dotted line exceeds 5 fps

Table C-7

FRICTION LOSS CHARACTERISTICS
PVC SCHEDULE 40 IPS PLASTIC PIPE

(1120, 1220) C = 150

PSI LOSS PER 100 FEET OF TUBE (PSI/100FT)

Sizes 4" thru 12"

Flow GPM 650 thru 5000

SIZE	4.00		5.00		6.00		8.00		10.00		12.00		SIZE
OD	4.500		5.563		6.625		8.625		10.750		12.750		OD
ID	4.026		5.047		6.065		7.981		10.020		11.814		ID
WALL THK	0.237		0.258		0.280		0.322		0.365		0.406		WALL THK
Flow G.P.M.	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Flow G.P.M.
650	16.36	7.86	10.41	2.62	7.20	1.07	4.16	0.28	2.64	0.09	1.90	0.04	650
700	17.62	9.02	11.21	3.00	7.76	1.23	4.48	0.32	2.84	0.11	2.04	0.05	700
750	18.87	10.25	12.01	3.41	8.31	1.40	4.80	0.37	3.04	0.12	2.19	0.05	750
800			12.81	3.85	8.87	1.57	5.12	0.41	3.25	0.14	2.33	0.06	800
850			13.61	4.30	9.42	1.76	5.44	0.46	3.45	0.15	2.48	0.07	850
900			14.41	4.78	9.98	1.96	5.76	0.51	3.65	0.17	2.63	0.08	900
950			15.21	5.29	10.53	2.16	6.08	0.57	3.86	0.19	2.77	0.08	950
1000			16.01	5.81	11.09	2.38	6.40	0.63	4.06	0.21	2.92	0.09	1000
1050			16.81	6.36	11.64	2.60	6.72	0.68	4.26	0.23	3.06	0.10	1050
1100			17.61	6.94	12.20	2.84	7.04	0.75	4.47	0.25	3.21	0.11	1100
1150			18.42	7.53	12.75	3.08	7.36	0.81	4.67	0.27	3.36	0.12	1150
1200			19.22	8.15	13.31	3.33	7.68	0.88	4.87	0.29	3.50	0.13	1200
1250					13.86	3.60	8.00	0.95	5.07	0.31	3.65	0.14	1250
1300					14.41	3.87	8.32	1.02	5.28	0.34	3.80	0.15	1300
1350					14.97	4.15	8.64	1.09	5.48	0.36	3.94	0.16	1350
1400					15.52	4.44	8.96	1.17	5.68	0.39	4.09	0.17	1400
1450					16.08	4.73	9.28	1.24	5.89	0.41	4.23	0.18	1450
1500					16.63	5.04	9.60	1.33	6.09	0.44	4.38	0.20	1500
1550					17.19	5.36	9.92	1.41	6.29	0.47	4.53	0.21	1550
1600					17.74	5.68	10.24	1.49	6.50	0.49	4.67	0.22	1600
1650					18.30	6.01	10.56	1.58	6.70	0.52	4.82	0.23	1650
1700					18.85	6.35	10.88	1.67	6.90	0.55	5.96	0.25	1700
1750					19.41	6.70	11.20	1.76	7.11	0.58	5.11	0.26	1750
1800					19.96	7.06	11.52	1.86	7.31	0.61	5.26	0.28	1800
1850							11.84	1.95	7.51	0.65	5.40	0.29	1850
1900							12.17	2.05	7.72	0.68	5.55	0.30	1900
1950							12.49	2.15	7.92	0.71	5.70	0.32	1950
2000							12.81	2.26	8.12	0.75	5.84	0.33	2000
2100							13.45	2.47	8.53	0.82	6.13	0.37	2100
2200							14.09	2.69	8.94	0.89	6.43	0.40	2200
2300							14.73	2.92	9.34	0.97	6.72	0.43	2300
2400							15.37	3.16	9.75	1.05	7.01	0.47	2400
2500							16.01	3.41	10.15	1.13	7.30	0.51	2500
2600							16.65	3.67	10.56	1.21	7.60	0.54	2600
2700							17.29	3.94	10.97	1.30	7.89	0.58	2700
2800							17.93	4.21	11.37	1.39	8.18	0.62	2800
2900							18.57	4.49	11.78	1.49	8.47	0.67	2900
3000							19.21	4.78	12.19	1.58	8.76	0.71	3000
3100							19.85	5.08	12.59	1.68	9.06	0.75	3100
3200									13.00	1.78	9.35	0.80	3200
3300									13.41	1.89	9.64	0.85	3300
3400									13.81	1.99	9.93	0.89	3400
3500									14.22	2.10	10.23	0.94	3500
3600									14.62	2.22	10.52	0.99	3600
3700									15.03	2.33	10.81	1.05	3700
3800									15.44	2.45	11.10	1.10	3800
3900									15.84	2.57	11.40	1.15	3900
4000									16.25	2.69	11.69	1.21	4000
4100									16.66	2.82	11.98	1.27	4100
4200									17.06	2.95	12.27	1.32	4200
4300									17.47	3.08	12.56	1.38	4300
4400									17.88	3.21	12.86	1.44	4400
4500									18.28	3.35	13.15	1.50	4500
4600									18.69	3.49	13.44	1.57	4600
4700									19.09	3.63	13.73	1.63	4700
4800									19.50	3.78	14.03	1.69	4800
4900									19.91	3.92	14.32	1.76	4900
5000											14.61	1.83	5000

locity below dotted line exceeds 5 fps

Table C-8

FRICTION LOSS CHARACTERISTICS
PVC SCHEDULE 80 IPS PLASTIC PIPE

(1120, 1220) C = 150

PSI LOSS PER 100 FEET OF TUBE (PSI/100 FT)

Sizes ½" thru 3½"

Flow GPM 1 thru 600

SIZE	0.50		0.75		1.00		1.25		1.50		2.00		2.50		3.00		3.50	
OD	0.840		1.050		1.315		1.660		1.900		2.375		2.875		3.500		4.000	
ID	0.546		0.742		0.957		1.278		1.500		1.939		2.323		2.900		3.364	
WALL THK	0.147		0.154		0.179		0.191		0.200		0.218		0.276		0.300		0.318	
Flow G.P.M.	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss
1	1.36	0.81	0.74	0.18	0.44	0.05	0.24	0.01	0.18	0.01	0.10	0.00						
2	2.73	2.92	1.48	0.66	0.89	0.19	0.49	0.05	0.36	0.02	0.21	0.01	0.15	0.00				
3	4.10	6.19	2.22	1.39	1.33	0.40	0.74	0.10	0.54	0.05	0.32	0.01	0.22	0.01				
4	5.47	10.54	2.96	2.37	1.78	0.69	0.99	0.17	0.72	0.08	0.43	0.02	0.30	0.01				
5	6.84	15.93	3.70	3.58	2.22	1.04	1.24	0.25	0.90	0.12	0.54	0.03	0.37	0.01	0.24	0.00		
6	8.21	22.33	4.44	5.02	2.67	1.46	1.49	0.36	1.08	0.16	0.65	0.05	0.45	0.02	0.29	0.01		
7	9.58	29.71	5.18	6.68	3.11	1.94	1.74	0.47	1.26	0.22	0.75	0.06	0.52	0.03	0.33	0.01	0.25	0.00
8	10.94	38.05	5.92	8.56	3.56	2.48	1.99	0.61	1.45	0.28	0.86	0.08	0.60	0.03	0.38	0.01	0.28	0.01
9	12.31	47.33	6.66	10.64	4.00	3.09	2.24	0.76	1.63	0.35	0.97	0.10	0.68	0.04	0.43	0.01	0.32	0.01
10	13.68	57.52	7.41	12.93	4.45	3.75	2.49	0.92	1.81	0.42	1.08	0.12	0.75	0.05	0.48	0.02	0.36	0.01
11	15.05	68.63	8.15	15.43	4.90	4.47	2.74	1.10	1.99	0.50	1.19	0.14	0.83	0.06	0.53	0.02	0.39	0.01
12	16.42	80.63	8.89	18.13	5.34	5.26	2.99	1.29	2.17	0.59	1.30	0.17	0.90	0.07	0.58	0.02	0.43	0.01
14			10.37	24.12	6.23	6.99	3.49	1.71	2.53	0.79	1.51	0.23	1.05	0.09	0.67	0.03	0.50	0.02
16			11.85	30.88	7.12	8.95	3.99	2.19	2.90	0.01	1.73	0.29	1.20	1.12	0.77	0.04	0.57	0.02
18			13.33	38.41	8.01	11.14	4.49	2.73	3.26	1.25	1.95	0.36	1.36	0.15	0.87	0.05	0.64	0.02
20			14.82	46.69	8.90	13.54	4.99	3.31	3.62	1.52	2.17	0.44	1.51	0.18	0.97	0.06	0.72	0.03
22			16.30	55.70	9.80	16.15	5.49	3.95	3.98	1.81	2.38	0.52	1.66	0.22	1.06	0.07	0.79	0.04
24			17.78	65.44	10.69	18.97	5.99	4.64	4.35	2.13	2.60	0.61	1.81	0.25	1.16	0.09	0.86	0.04
26			19.26	75.90	11.58	22.01	6.49	5.39	4.71	2.47	2.82	0.71	1.96	0.29	1.26	0.10	0.93	0.05
28					12.47	25.24	6.99	6.18	5.07	2.83	3.03	0.81	2.11	0.34	1.35	0.11	1.00	0.06
30					13.36	28.69	7.49	7.02	5.43	3.22	3.25	0.92	2.26	0.38	1.45	0.13	1.08	0.06
35					15.59	38.16	8.74	9.34	6.34	4.29	3.79	1.23	2.64	0.51	1.69	0.17	1.26	0.08
40					17.81	48.87	9.99	11.96	7.25	5.49	4.34	1.57	3.02	0.65	1.94	0.22	1.44	0.11
45							11.24	14.88	8.16	6.23	4.88	1.96	3.40	0.81	2.18	0.28	1.62	0.13
50							12.49	18.09	9.06	6.30	5.42	2.38	3.78	0.99	2.42	0.34	1.80	0.16
55							13.73	21.58	9.97	9.90	5.96	2.84	4.15	1.18	2.66	0.40	1.98	0.19
60							14.98	25.35	10.87	11.63	6.51	3.33	4.53	1.38	2.91	0.47	2.16	0.23
65							16.23	29.40	11.78	13.49	7.05	3.87	4.91	1.61	3.15	0.55	2.34	0.27
70							17.48	33.72	12.69	15.47	7.59	4.44	5.29	1.84	3.39	0.63	2.52	0.30
75							18.73	38.32	13.59	17.58	8.13	5.04	5.67	2.09	3.63	0.71	2.70	0.35
80							19.98	43.19	14.50	19.81	8.68	5.68	6.04	2.36	3.88	0.80	2.88	0.39
85									15.41	22.16	9.22	6.36	6.42	2.63	4.12	0.90	3.06	0.44
90									16.32	24.64	9.76	7.07	6.80	2.93	4.36	1.00	3.24	0.48
95									17.22	27.23	10.30	7.81	7.18	3.24	4.60	1.10	3.42	0.54
100									18.13	29.95	10.85	8.59	7.56	3.57	4.85	1.21	3.60	0.59
110									19.94	35.73	11.93	10.25	8.31	4.25	5.33	1.45	3.96	0.70
120											13.02	12.04	9.07	5.00	5.82	1.70	4.32	0.82
130											14.10	13.96	9.82	5.60	6.30	1.97	4.68	0.96
140											15.19	16.02	10.58	6.65	6.79	2.27	5.04	1.10
150											16.27	18.20	11.34	7.56	7.27	2.57	5.40	1.25
160											17.36	20.51	12.09	8.51	7.76	2.89	5.76	1.41
170											18.44	22.95	12.85	9.53	8.24	3.24	6.12	1.57
180											19.53	25.51	13.60	10.59	8.73	3.60	6.48	1.75
190													14.36	11.71	9.21	3.98	6.85	1.93
200													15.12	12.87	9.70	4.37	7.21	2.12
225													17.01	16.01	10.91	5.44	8.11	2.64
250													18.90	19.46	12.12	6.61	9.01	3.21
275															13.34	7.89	9.91	3.83
300															14.55	9.27	10.81	4.50
325															15.76	10.75	11.71	5.22
350															16.97	12.33	12.61	5.99
375															18.19	14.01	13.52	6.81
400															19.40	15.79	14.42	7.67
425																	15.32	8.58
450																	16.22	9.54
475																	17.12	10.54
500																	18.02	11.51
550																	19.82	13.83
600																		

Velocity below dotted line exceeds 5 fps

FRICTION LOSS CHARACTERISTICS
PVC SCHEDULE 80 IPS PLASTIC PIPE

(1120, 1220) C = 150
PSI LOSS PER 100 FEET OF TUBE (PSI/100 FT)

Sizes 4" thru 12"
Flow GPM 1 thru 600

SIZE	4.00	5.00	6.00	8.00	10.00	12.00	SIZE
OD	4.500	5.563	6.625	8.625	10.750	12.750	OD
ID	3.826	4.813	5.761	7.625	9.564	11.376	ID
WALL THK	0.337	0.375	0.432	0.500	0.593	0.687	WALL THK

Flow G.P.M.	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Flow G.P.M.
1													1
2													2
3													3
4													4
5													5
6													6
7													7
8													8
9													9
10	0.27	0.00											10
11	0.30	0.01											11
12	0.33	0.01											12
14	0.39	0.01											14
16	0.44	0.01											16
18	0.50	0.01	0.31	0.00									18
20	0.55	0.02	0.35	0.01									20
22	0.61	0.02	0.38	0.01									22
24	0.66	0.02	0.42	0.01									24
26	0.72	0.03	0.45	0.01									26
28	0.78	0.03	0.49	0.01									28
30	0.83	0.03	0.52	0.01	0.36	0.00							30
35	0.97	0.05	0.61	0.01	0.43	0.01							35
40	1.11	0.06	0.70	0.02	0.49	0.01							40
45	1.25	0.07	0.79	0.02	0.55	0.01							45
50	1.39	0.09	0.88	0.03	0.61	0.01							50
55	1.53	0.10	0.96	0.03	0.67	0.01							55
60	1.67	0.12	1.05	0.04	0.73	0.02							60
65	1.81	0.14	1.14	0.05	0.79	0.02	0.45	0.00					65
70	1.95	0.16	1.23	0.05	0.86	0.02	0.49	0.01					70
75	2.09	0.18	1.32	0.06	0.92	0.03	0.52	0.01					75
80	2.22	0.21	1.40	0.07	0.98	0.03	0.56	0.01					80
85	2.36	0.23	1.49	0.08	1.04	0.03	0.59	0.01					85
90	2.50	0.26	1.58	0.08	1.10	0.04	0.63	0.01					90
95	2.64	0.29	1.67	0.09	1.16	0.04	0.66	0.01					95
100	2.78	0.31	1.76	0.10	1.22	0.04	0.70	0.01					100
110	3.06	0.38	1.93	0.12	1.35	0.05	0.77	0.01	0.49	0.00			110
120	3.34	0.44	2.11	0.14	1.47	0.06	0.84	0.02	0.53	0.01			120
130	3.62	0.51	2.28	0.17	1.59	0.07	0.91	0.02	0.57	0.01			130
140	3.90	0.59	2.46	0.19	1.72	0.08	0.98	0.02	0.62	0.01			140
150	4.18	0.67	2.64	0.22	1.84	0.09	1.05	0.02	0.66	0.01			150
160	4.45	0.75	2.81	0.25	1.96	0.10	1.12	0.03	0.71	0.01			160
170	4.73	0.84	2.99	0.28	2.08	0.11	1.19	0.03	0.75	0.01			170
180	5.01	0.93	3.17	0.31	2.21	0.13	1.26	0.03	0.80	0.01	0.56	0.00	180
190	5.29	1.03	3.34	0.34	2.33	0.14	1.33	0.04	0.84	0.01	0.59	0.01	190
200	5.57	1.14	3.52	0.37	2.45	0.16	1.40	0.04	0.89	0.01	0.63	0.01	200
225	6.27	1.41	3.96	0.46	2.76	0.19	1.57	0.05	1.00	0.02	0.70	0.01	225
250	6.96	1.72	4.40	0.56	3.07	0.23	1.75	0.06	1.11	0.02	0.78	0.01	250
275	7.66	2.05	4.84	0.67	3.38	0.28	1.92	0.07	1.22	0.02	0.86	0.01	275
300	8.36	2.41	5.28	0.79	3.68	0.33	2.10	0.08	1.33	0.03	0.94	0.01	300
325	9.05	2.79	5.72	0.91	3.99	0.38	2.28	0.10	1.44	0.03	1.02	0.01	325
350	9.75	3.20	6.16	1.05	4.30	0.44	2.45	0.11	1.56	0.04	1.10	0.02	350
375	10.45	3.64	6.60	1.19	4.60	0.50	2.63	0.13	1.67	0.04	1.18	0.02	375
400	11.14	4.10	7.04	1.34	4.91	0.56	2.80	0.14	1.78	0.05	1.26	0.02	400
425	11.84	4.59	7.48	1.50	5.22	0.63	2.98	0.16	1.89	0.05	1.33	0.02	425
450	12.54	5.10	7.92	1.67	5.53	0.70	3.15	0.18	2.00	0.06	1.41	0.03	450
475	13.23	5.64	8.36	1.85	5.83	0.77	3.33	0.20	2.11	0.07	1.49	0.03	475
500	13.93	6.20	8.80	2.03	6.14	0.85	3.50	0.22	2.23	0.07	1.57	0.03	500
550	15.32	7.40	9.68	2.42	6.76	1.01	3.85	0.26	2.45	0.09	1.73	0.04	550
600	16.72	8.69	10.56	2.84	7.37	1.19	4.21	0.30	2.67	0.10	1.89	0.04	600

Velocity below dotted line exceeds 5 fps

Table C-10

FRICTION LOSS CHARACTERISTICS
PVC SCHEDULE 80 IPS PLASTIC PIPE
(1120, 1220) C = 150
PSI LOSS PER 100 FEET OF TUBE (PSI/100 FT)
Sizes 4" thru 12"
Flow GPM 650 thru 5000

SIZE	4.00	5.00	6.00	8.00	10.00	12.00	SIZE
OD	4.500	5.563	6.625	8.625	10.750	12.750	OD
ID	3.826	4.813	5.761	7.625	9.564	11.376	ID
WALL THK	0.337	0.375	0.432	0.500	0.593	0.687	WALL THK

Flow G.P.M.	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Flow G.P.M.
650	18.11	10.08	11.44	3.30	7.99	1.38	4.56	0.35	2.89	0.12	2.04	0.05	650
700	19.51	11.56	12.32	3.78	8.60	1.58	4.91	0.40	3.12	0.13	2.20	0.06	700
750			13.20	4.30	9.21	1.79	5.26	0.46	3.34	0.15	2.36	0.07	750
800			14.09	4.85	9.83	2.02	5.61	0.52	3.56	0.17	2.52	0.07	800
850			14.97	5.42	10.44	2.26	5.96	0.58	3.79	0.19	2.67	0.08	850
900			15.85	6.03	11.06	2.51	6.31	0.64	4.01	0.21	2.83	0.09	900
950			16.73	6.66	11.67	2.78	6.66	0.71	4.23	0.24	2.99	0.10	950
1000			17.61	7.33	12.29	3.05	7.01	0.78	4.46	0.26	3.15	0.11	1000
1050			18.49	8.02	12.90	3.34	7.36	0.85	4.68	0.28	3.31	0.12	1050
1100			19.37	8.74	13.52	3.64	7.71	0.93	4.90	0.31	3.46	0.13	1100
1150					14.13	3.96	8.07	1.01	5.12	0.34	3.62	0.14	1150
1200					14.75	4.28	8.42	1.09	5.35	0.36	3.78	0.16	1200
1250					15.36	4.62	8.77	1.18	5.57	0.39	3.94	0.17	1250
1300					15.98	4.97	9.12	1.27	5.79	0.42	4.09	0.18	1300
1350					16.59	5.33	9.47	1.36	6.02	0.45	4.25	0.19	1350
1400					17.21	5.70	9.82	1.46	6.24	0.48	4.41	0.21	1400
1450					17.82	6.08	10.17	1.55	6.46	0.62	4.57	0.22	1450
1500					18.43	6.47	10.52	1.65	6.69	0.55	4.72	0.24	1500
1550					19.05	6.88	10.87	1.76	6.91	0.58	4.88	0.25	1550
1600					19.66	7.29	11.22	1.86	7.13	0.62	5.04	0.27	1600
1650							11.57	1.97	7.35	0.66	5.20	0.28	1650
1700							11.92	2.09	7.58	0.69	5.35	0.30	1700
1750							12.28	2.20	7.80	0.73	5.51	0.31	1750
1800							12.63	2.32	8.02	0.77	5.67	0.33	1800
1850							12.98	2.44	8.25	0.81	5.83	0.35	1850
1900							13.33	2.56	8.47	0.85	5.99	0.37	1900
1950							13.68	2.69	8.69	0.89	6.14	0.38	1950
2000							14.03	2.82	8.92	0.94	6.30	0.40	2000
2100							14.73	3.09	9.36	1.02	6.62	0.44	2100
2200							15.43	3.36	9.81	1.12	6.93	0.48	2200
2300							16.14	3.65	10.25	1.21	7.25	0.52	2300
2400							16.84	3.95	10.70	1.31	7.56	0.56	2400
2500							17.54	4.26	11.15	1.42	7.88	0.61	2500
2600							18.24	4.58	11.59	1.52	8.19	0.65	2600
2700							18.94	4.91	12.04	1.63	8.51	0.70	2700
2800							19.64	5.26	12.48	1.75	8.82	0.75	2800
2900									12.93	1.86	9.14	0.80	2900
3000									13.38	1.98	9.45	0.85	3000
3100									13.82	2.11	9.77	0.91	3100
3200									14.27	2.24	10.08	0.96	3200
3300									14.71	2.37	10.40	1.02	3300
3400									15.16	2.50	10.71	1.08	3400
3500									15.61	2.64	11.03	1.13	3500
3600									16.05	2.78	11.34	1.20	3600
3700									16.50	2.93	11.66	1.26	3700
3800									16.94	3.07	11.98	1.32	3800
3900									17.39	3.22	12.29	1.39	3900
4000									17.84	3.38	12.61	1.45	4000
4100									18.28	3.54	12.92	1.52	4100
4200									18.73	3.70	13.24	1.59	4200
4300									19.17	3.86	13.55	1.66	4300
4400									19.62	4.03	13.87	1.73	4400
4500											14.18	1.81	4500
4600											14.50	1.88	4600
4700											14.81	1.96	4700
4800											15.13	2.04	4800
4900											15.44	2.12	4900
5000											15.76	2.20	5000

Velocity below dotted line exceeds 5 fps

Table C-11. Friction loss in feet per 100 feet in asbestos cement pressure pipe

Flow (gallons per minute)	4	6	8	10	12
	I.D. = 3.95	I.D. = 5.85	I.D. = 7.85	I.D. = 10.00	I.D. = 12.00
100	0.677				
120	.954				
140	1.28				
160	1.65				
180	2.06				
200	2.53	0.372			
220	3.03	.447			
240	3.56	.525			
260	4.16	.611			
280	4.77	.705			
300	5.44	.803			
320	6.16	.910			
340	6.91	1.02			
360	7.70	1.14			
380	8.54	1.26			
400	9.40	1.39	0.324		
420	10.3	1.52	.355		
440	11.3	1.66	.389		
460	12.3	1.81	.423		
480	13.3	1.96	.458		
500	14.4	2.12	.495		
550	17.2	2.55	.594		
600	20.3	2.99	.701	0.214	
650	23.7	3.49	.818	.249	
700	27.3	4.02	.935	.287	
750	31.1	4.57	1.07	.328	
800		5.18	1.21	.370	0.152
850		5.81	1.36	.415	.170
900		6.46	1.51	.464	.190
950		7.17	1.68	.511	.210
1000		7.91	1.85	.564	.232
1100		9.45	2.21	.675	.278
1200		11.2	2.62	.800	.328
1300		13.0	3.04	.932	.384
1400		15.0	3.50	1.07	.438
1500		17.1	3.99	1.22	.502
1600		19.3	4.52	1.38	.566
1700			5.06	1.55	.637
1800			5.67	1.73	.710
1900			6.26	1.91	.787
2000			6.90	2.11	.864
2200			8.27	2.53	1.04
2400			9.75	2.98	1.23
2600			11.4	3.47	1.43
2800			13.1	4.00	1.64
3000			14.9	4.56	1.87

From Scobey's formula

$$H_f = K_s \frac{V^{1.9}}{D^{1.1}}$$

where H_f = head loss in 1000 feet of pipe

K_s = roughness coefficient = 0.32

V = velocity in feet per second

D = inside pipe diameter in feet

Velocity of values below dotted line exceed 5 fps

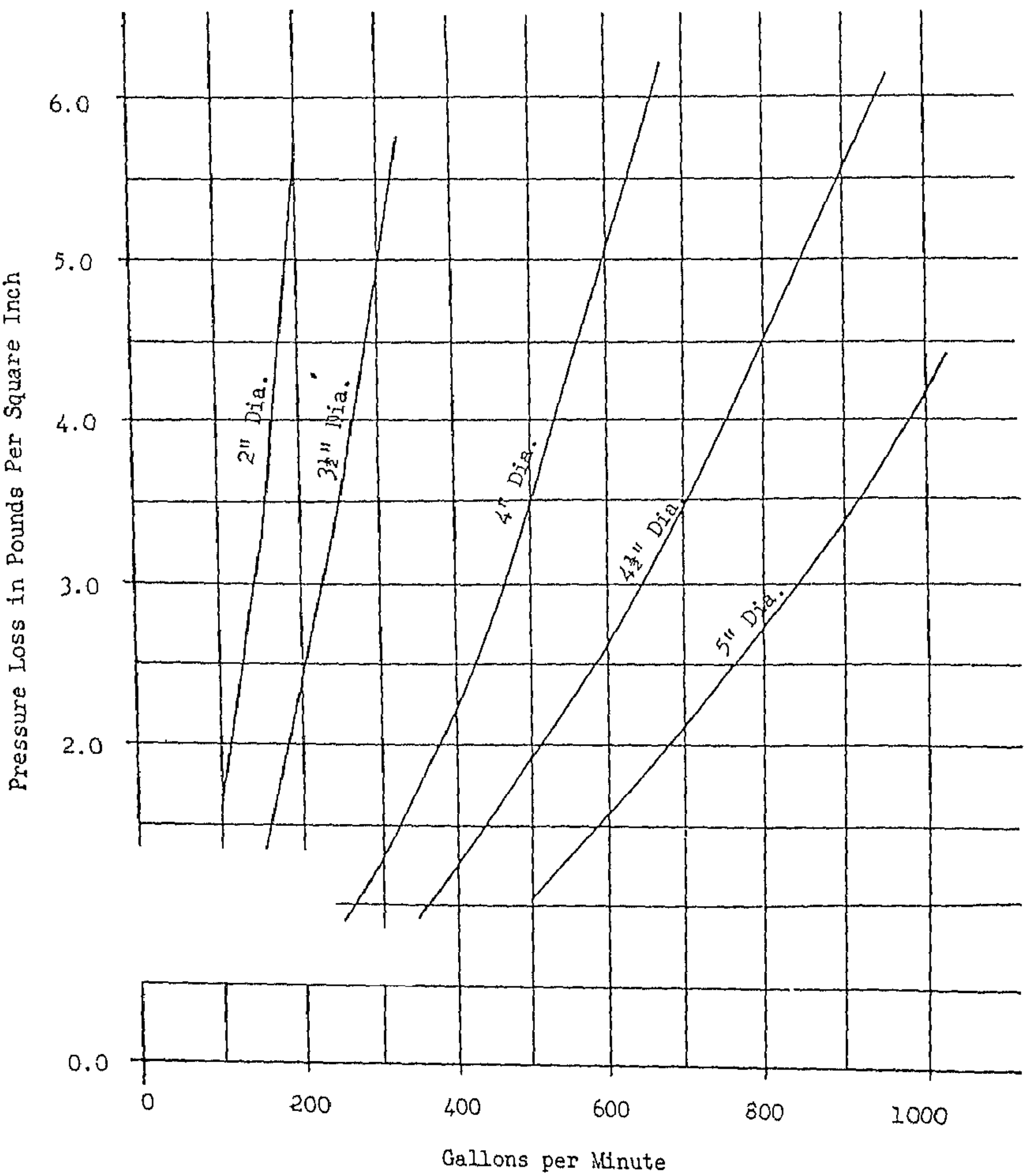
TABLE C-12. PRESSURE (FRICTION) LOSS, IN FEET PER 100 FEET, FOR PORTABLE ALUMINUM IRRIGATION PIPE WITH COUPLINGS. (BASED ON SCOBEY'S FORMULA K_s = 0.40, AND 30-FT. PIPE LENGTHS.)[1/]

Gallons Per Minute	Pipe Diameters						
	3-in. OD 2.914 ID	4-in. OD 3.906 ID	5-in. OD 4.896 ID	6-in. OD 5.884 ID	7-in. OD 6.872 ID	8-in. OD 7.856 ID	10-in. OD 9.818 ID
40	.658	.157					
50	1.006	.239					
60	1.423	.339					
70	1.906	.449	.150				
80	2.457	.584	.193				
90	3.073	.731	.242				
100	3.754	.893	.295	.120			
120	5.307	1.263	.417	.170			
140	7.113	1.693	.560	.227			
160	9.169	2.182	.721	.293			
180	11.47	2.729	.967	.366			
200	14.01	3.333	1.102	.448	.209		
220	16.79	3.996	1.321	.537	.251		
240	19.81	4.713	1.558	.633	.296		
260	23.06	5.488	1.814	.737	.344		
280	26.55	6.316	2.089	.849	.397		
300	30.27	7.203	2.381	.967	.452	.235	
320	34.22	8.142	2.692	1.094	.511	.265	
340	38.39	9.137	3.020	1.227	.573	.298	
360	42.80	10.18	3.366	1.368	.639	.332	
380	47.43	11.29	3.731	1.516	.708	.368	
400	52.28	12.44	4.113	1.671	.781	.399	.136
420		13.65	4.513	1.833	.857	.445	.149
440		14.57	4.930	1.988	.936	.486	.163
460		16.23	5.364	2.179	1.019	.529	.177
480		17.59	5.815	2.363	1.104	.573	.192
500		19.01	6.284	2.554	1.193	.620	.208
550		22.79	7.532	3.060	1.430	.742	.249
600		26.88	8.886	3.611	1.687	.876	.294
650		31.30	10.35	4.204	1.965	1.020	.342
700		36.03	11.91	4.839	2.262	1.174	.394
750		41.08	13.58	5.517	2.520	1.339	.449
800			15.35	6.237	2.915	1.513	.507
850			17.22	6.999	3.271	1.698	.569
900			19.20	7.801	3.646	1.893	.635
950			21.28	8.645	4.041	2.097	.703
1000			23.45	9.530	4.454	2.312	.775
1100			28.11	11.42	5.338	2.771	.929
1200			31.75	13.58	6.298	3.269	1.096
1300				15.69	7.333	3.806	1.277
1400				18.06	8.441	4.382	1.470
1500				20.59	9.264	4.996	1.675
1600				23.28	10.88	5.648	1.894
1700				26.12	12.21	6.337	2.125
1800					13.61	7.064	2.369
1900					15.08	7.829	2.625
2000					16.62	8.630	2.894

1/ For 20-ft pipe lengths, increase values in the table by 7.0 percent. For 40-ft lengths, decrease values by 3.0 percent. Velocity of values below dotted line exceed 5 fps.

Exhibit C-1

FLEXIBLE IRRIGATION HOSE
PRESSURE LOSS PER 100 FEET OF LENGTH



FRICTION LOSS CHARACTERISTICS
POLYETHYLENE (PE) SDR-PRESSURE RATED TUBE

(2306, 3206, 3306) SDR 7, 9, 11 5, 15 C = 140
PSI LOSS PER 100 FEET OF TUBE (PSI/100 FT)

Sizes 1/2" thru 6"
Flow GPM 1 thru 1800

SIZE	0 50	0 75	1 00	1 25	1 50	2 00	2 50	3.00	4 00	6 00
OD	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0.000	0 000	0 000
ID	0 622	0 824	1 049	1 380	1 610	2 067	2 469	3 068	4,026	6 065
WALL THK	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000

Flow G.P.M.	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss	Velocity F.P.S.	P.S.I. Loss
1	1 05	0 49	0 60	0 12	0 37	0 04	0 21	0 01	0 15	0 00	0 09	0 00								
2	2 10	1 76	1 20	0 45	0 74	0 14	0 42	0 04	0 31	0 02	0 19	0 01								
3	3 16	3 73	1 80	0 95	1 11	0 29	0 64	0 08	0 47	0 04	0 28	0 01	0 20	0 00						
4	4 21	6 35	2 40	1 62	1 48	0 50	0 85	0 13	0 62	0 06	0 38	0 02	0 26	0 01						
5	5 27	9 60	3 00	2 44	1 85	0 76	1 07	0 20	0 78	0 09	0 47	0 03	0 33	0 01	0 21	0 00				
6	6 32	13 46	3 60	3 43	2 22	1 06	1 28	0 28	0 94	0 13	0 57	0 04	0 40	0 07	0 26	0 01				
7	7 38	17 91	4 20	4 56	2 59	1 41	1 49	0 37	1 10	0 18	0 66	0 05	0 46	0 02	0 30	0 01				
8	8 43	22 93	4 80	5 84	2 96	1 80	1 71	0 47	1 25	0 22	0 76	0 07	0 53	0 03	0 34	0 01				
9	9 49	28 52	5 40	7 26	3 33	2 24	1 92	0 59	1 41	0 28	0 85	0 09	0 60	0 03	0 39	0 01				
10	10 54	34 67	6 00	8 82	3 70	2 73	2 14	0 72	1 57	0 34	0 95	0 10	0 66	0 04	0 43	0 01				
11	11 60	41 36	6 00	10 53	4 07	3 25	2,35	0 86	1 73	0 40	1 05	0 12	0 73	0 05	0 47	0 02	0 27	0 00		
12	12 65	48 60	7 21	12 37	4 44	3 82	2 57	1 01	1 88	0 48	1 14	0 14	0 80	0 06	0 52	0 02	0 30	0 01		
14	14 76	64 65	8 41	16 46	5.19	5.08	2 99	1 34	2 20	0 63	1 33	0 19	0 93	0 08	0 60	0 03	0 35	0 01		
16	16 87	82 79	9 61	21 07	5 93	6 51	3 42	1 71	2.51	0 81	1 52	0 24	1 07	0 10	0 69	0 04	0 40	0 01		
18	18 98	02 97	10 81	26 21	6 67	8.10	3 85	2.13	2 83	1 01	1 71	0 30	1 20	0 13	0 78	0 04	0 45	0 01		
20			12 01	31 86	7 41	9 84	4 28	2 59	3 14	1 22	1 90	0 36	1 33	0 15	0 86	0 05	0 50	0 01		
22			13 21	38 01	8 15	11 74	4 71	3 09	3.46	1 46	2 10	0 43	1 47	0 18	0 95	0 06	0 55	0 02		
24			14 42	44 65	8 89	13 79	5 14	3 63	3 77	1 72	2 29	0 51	1 60	0 21	1 04	0 07	0 60	0 02		
26			15 62	41 79	9 64	16 00	5.57	4 21	4.09	1 99	2 48	0 59	1 74	0 25	1 12	0 09	0 65	0 02		
28			16 82	59 41	10 38	18 35	5 99	4 83	4 40	2 28	2 67	0 68	1 87	0 29	1 21	0 10	0 70	0 03		
30			18 02	67 50	11 12	20 85	6 42	5 49	4 72	2 59	2 86	0 77	2 00	0 32	1 30	0 11	0 75	0 03	0 33	0 0
35					12 97	27.74	7.49	7 31	5 50	3 45	3 34	1 02	2 34	0 43	1 51	0 15	0 88	0 04	0.38	0 0
40					14 83	35 53	8.56	9.36	6 29	4 42	3 81	1 31	2 67	0 55	1 73	0 19	1 00	0 05	0 44	0 0
45					16 68	44 19	9.64	11 64	7 08	5 50	4 29	1 63	3 01	0 69	1 95	0 24	1 13	0 06	0.49	0 0
50					18 53	53.71	10.71	14.14	7 87	6.68	4.77	1.98	3 34	0 83	2 16	0 29	1 25	0 08	0 55	0 0
55							11 78	16 87	8 65	7 97	5 25	2 36	3 68	1 00	2 38	0 35	1 38	0 09	0.61	0 0
60							12.85	19 82	9 44	9 36	5 72	2,78	4 01	1 17	2 60	0 41	1 51	0 11	0,66	0 0
65							13.92	22 99	10 23	10 86	6 20	3 22	4.35	1 36	2 81	0 47	1 63	0 13	0 72	0 0
Flow GPM 650 thru 1800							14 99	26 37	11 01	12 46	6 68	3,69	4 68	1 56	3 03	0 54	1 76	0 14	0 77	0 0
SIZE	4 00		6 00				16 06	29.97	11 80	14 16	7 16	4 20	5 01	1 77	3 25	0 61	1 88	0 16	0.83	0 0
OD	0 000		0 000				17 13	33 77	12 59	15 95	7 63	4 73	5.35	1 99	3 46	0.69	2 01	0 18	0 88	0 0
ID	4 026		6 065				18 21	37 79	13 37	17 85	8 11	5 29	5 68	2 73	3 68	0 77	2 13	0 21	0 94	0 0
							19 28	42 01	14,16	19 84	8 59	5 88	6 02	2 48	3 90	0 86	2 26	0 23	0 99	0.0
WALL	0 000		0 000						14.95	21 93	9 07	6 50	6.35	2 74	4 11	0 95	2 39	0 25	1 05	0 0
THK									15 74	24 12	9 54	7,15	6 69	3 01	4 33	1 05	2 51	0 28	1 10	0 0
650	16 36	8 94	7 20	1 22					17 31	28 77	10 50	8 53	7 36	3 59	4 76	1 25	2 76	0 33	1 22	0 0
700	17 62	10 25	7 76	1 40					18 88	33 80	11.45	10 02	8.03	4.22	5.20	1 47	3 02	0 39	1 33	0 0
750	18 87	11 65	8 31	1 59							12 41	11 62	8.70	4 90	5 63	1 70	3 27	0 45	1 44	0.0
800			8 87	1 79							13.36	13 33	9.37	5 62	6 06	1 95	3 52	0 52	1,55	0.0
850			9 42	2 00							14 32	15 15	10.03	6 38	6 50	2 22	3 77	0 59	1 66	0 0
900			9 98	2 22							15.27	17 08	10.70	7 19	6 93	2 50	4 02	0 67	1 77	0 0
950			10 53	2 46							16.23	19 11	11.37	8 05	7 36	2 80	4 27	0 75	1 88	0 1
1000			11 09	2 70							17 18	21 24	12 04	8.95	7.08	3 11	4 53	0 83	1 99	0 1
1050			11.64	2 96							18.14	23.48	12 71	9 89	8.23	3 44	4 78	0 92	2.10	0 1
1100			12 20	3,22							19 09	25 81	13.38	10 87	8 66	3 78	5 03	1.01	2.21	0 1
1150			12 75	3 50									15.05	13 52	9.75	4 70	5.66	1.25	2 49	0 1
1200			13 31	3,79									16.73	16 44	10 83	5 71	6,29	1 52	2 77	0
1250			13 86	4 09									18 40	19 61	11 92	6 82	6 92	1 82	3.05	0
1300			14 41	4 39											13 00	8 01	7 55	2,13	3.32	0
1350			14 97	4,71											14 08	9 29	8 18	2 48	3.60	0.
1400			15 52	5 04											15 17	10 65	8.81	2 84	3 88	0
1450			16 08	5 38											16.25	12.10	9.43	3 23	4.15	0
1500			16 63	5 73											17.33	13 64	10 06	3 64	4.43	0
1550			17 19	6 09											18 42	15 26	10 69	4 07	4 71	0
1600			17 74	6 45											19 50	16 97	11.32	4 52	4 99	0
1650			18 30	6 83													11 95	5.00	5 26	0.
1700			18 85	7 22													12 58	5 50	5.54	0.
1750			19 41	7 62													13 84	6.56	6,10	0.
1800			19 96	8.03													15 10	7 70	6.65	1.

Exhibit C-2. FRICTION LOSS IN POLYETHYLENE PIPE

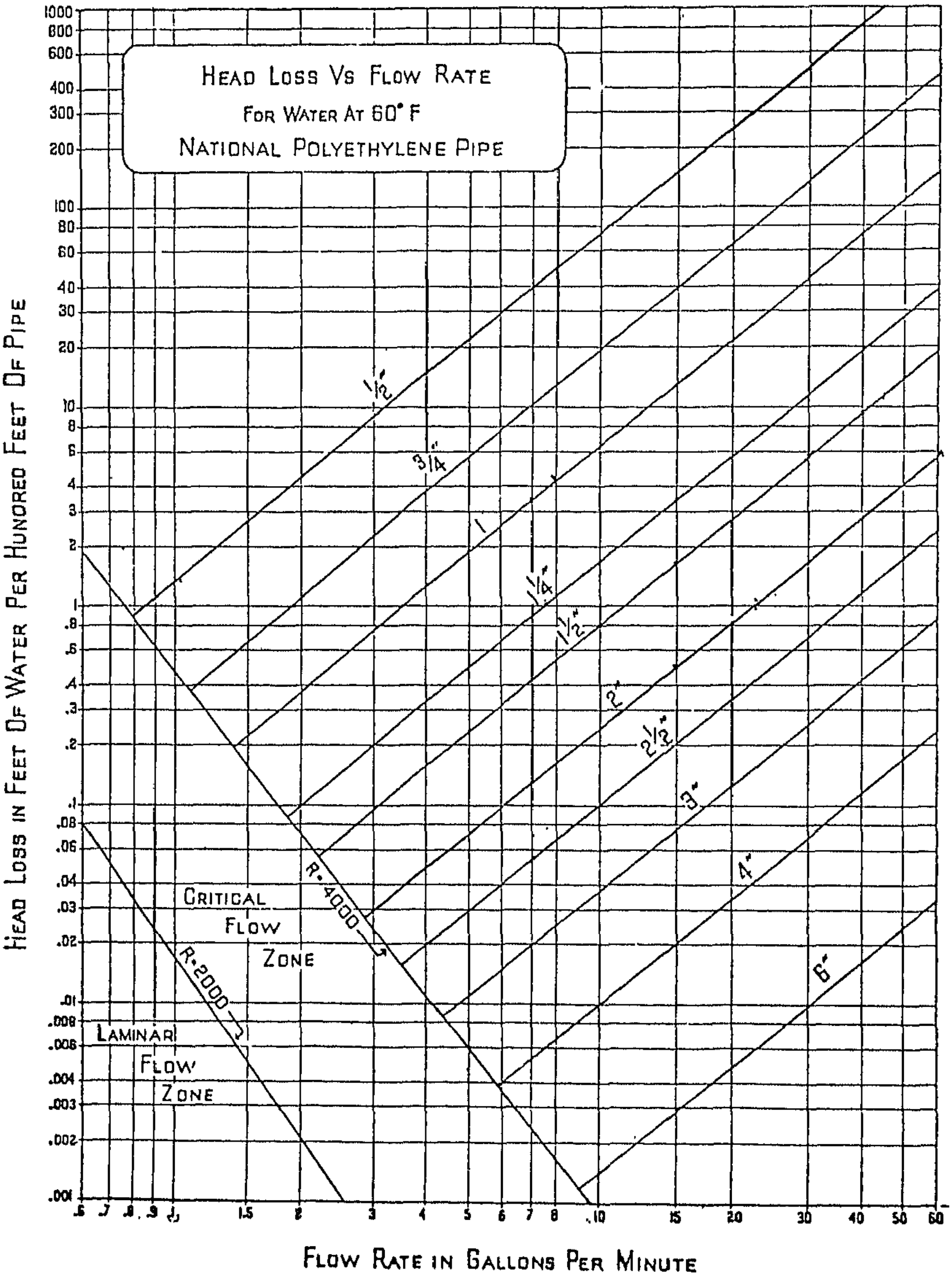


Table C-14

FEEDER LINE FRICTION LOSS (PER 100 FEET)

3/4 (.800 ID)				1/2 (.580 ID)				3/8 (.375 ID)			
Flow in GPH	Flow in GPM	Friction Loss in psi	Velocity Feet Sec	Flow in GPH	Flow in GPM	Friction Loss in psi	Velocity Feet Sec	Flow in GPH	Flow in GPM	Friction Loss in psi	Velocity Feet Sec
36	0.60	0.05	0.38	18	0.30	0.07	0.37	0.6	0.01	0.001	0.03
42	0.70	0.07	0.45	24	0.40	0.11	0.49	1.8	0.03	0.007	0.09
48	0.80	0.08	0.51	30	0.50	0.17	0.61	3.0	0.05	[illegible]	0.15
54	0.90	0.10	0.57	36	0.60	0.23	0.73	6.0	0.10	[illegible]	0.29
60	1.00	0.13	0.64	42	0.70	0.31	0.85	12.0	0.20	0.27	0.58
66	1.10	0.15	0.70	48	0.80	0.40	0.96	18.0	0.30	0.54	0.87
72	1.20	0.18	0.77	54	0.90	0.50	1.10	24.0	0.40	0.92	1.16
78	1.30	0.21	0.83	60	1.00	0.60	1.22	30.0	0.50	1.39	1.45
84	1.40	0.24	0.89	66	1.10	0.72	1.34	36.0	0.60	1.95	1.74
90	1.50	0.27	0.96	72	1.20	0.85	1.46	42.0	0.70	2.60	2.03
96	1.60	0.30	1.02	78	1.30	0.98	1.58	48.0	0.80	3.32	2.32
102	1.70	0.34	1.09	84	1.40	1.12	1.70	54.0	0.90	4.14	2.61
108	1.80	0.37	1.15	90	1.50	1.28	1.82	60.0	1.00	5.02	2.90
114	1.90	0.41	1.21	96	1.60	1.44	1.95	66.0	1.10	5.98	3.19
120	2.00	0.45	1.28	102	1.70	1.61	2.07	72.0	1.20	7.05	3.48
126	2.10	0.50	1.34	108	1.80	1.79	2.19	78.0	1.30	8.17	3.77
132	2.20	0.54	1.40	114	1.90	1.98	2.31	84.0	1.40	9.36	4.06
138	2.30	0.59	1.47	120	2.00	2.17	2.44	90.0	1.50	10.65	4.35
144	2.40	0.64	1.53	126	2.10	2.38	2.56	96.0	1.60	12.00	4.64
150	2.50	0.69	1.60	132	2.20	2.59	2.68	102.0	1.70	13.43	4.93
156	2.60	0.74	1.66	138	2.30	2.82	2.80	108.0	1.80	14.94	5.22
162	2.70	0.79	1.72	144	2.40	3.05	2.92	114.0	1.90	16.40	5.51
168	2.80	0.85	1.79	150	2.50	3.29	3.04	120.0	2.00	18.13	5.80
174	2.90	0.90	1.85	156	2.60	3.53	3.16				
180	3.00	0.96	1.91	162	2.70	3.79	3.28				
186	3.10	1.02	1.98	168	2.80	4.05	3.41				
192	3.20	1.08	2.04	174	2.90	4.32	3.53				
198	3.30	1.15	2.11	180	3.00	4.60	3.65				
204	3.40	1.21	2.17	186	3.10	4.89	3.77				
210	3.50	1.28	2.23	192	3.20	5.19	3.89				
216	3.60	1.35	2.30	198	3.30	5.49	4.02				
222	3.70	1.42	2.36	204	3.40	5.80	4.12				
228	3.80	1.49	2.42	210	3.50	6.12	4.25				
234	3.90	1.56	2.49	216	3.60	6.45	4.37				
240	4.00	1.64	2.55	222	3.70	6.78	4.49				
246	4.10	1.71	2.62	228	3.80	7.13	4.61				
252	4.20	1.79	2.68	234	3.90	7.48	4.73				
258	4.30	1.87	2.74	240	4.00	7.84	4.85				
264	4.40	1.95	2.81								
270	4.50	2.04	2.87								
276	4.60	2.12	2.94								
282	4.70	2.21	3.00								
288	4.80	2.29	3.06								
294	4.90	2.38	3.13								
300	5.00	2.47	3.19								
306	5.10	2.57	3.25								
312	5.20	2.66	3.32								
318	5.30	2.76	3.38								
324	5.40	2.85	3.45								
330	5.50	2.95	3.51								
336	5.60	3.05	3.57								
342	5.70	3.15	3.64								
348	5.80	3.26	3.70								
354	5.90	3.36	3.76								
360	6.00	3.47	3.83								
366	6.10	3.58	3.89								
372	6.20	3.68	3.96								
378	6.30	3.79	4.02								
384	6.40	3.91	4.08								
390	6.50	4.02	4.15								
396	6.60	4.14	4.21								
402	6.70	4.25	4.28								
408	6.80	4.37	4.34								
414	6.90	4.49	4.40								
420	7.00	4.61	4.47								
426	7.10	4.73	4.53								
432	7.20	4.86	4.57								
438	7.30	4.98	4.66								
444	7.40	5.11	4.72								
450	7.50	5.24	4.79								
456	7.60	5.37	4.85								
462	7.70	5.50	4.91								
468	7.80	5.63	4.98								
474	7.90	5.77	5.04								
480	8.00	5.90	5.10								

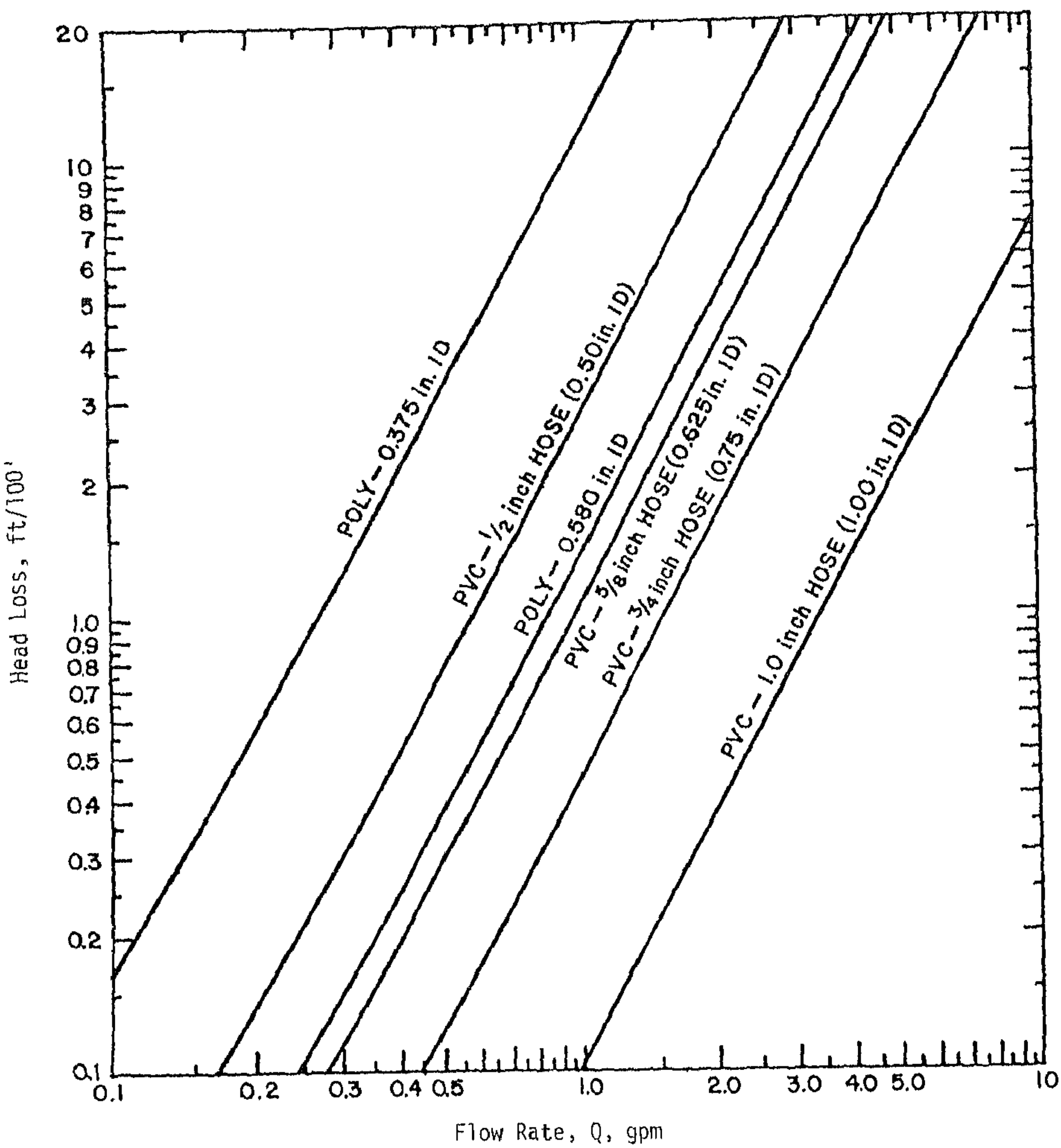


Exhibit C-3. Friction head loss as a function of flow rate for lateral tubing manufactured in English dimensions.

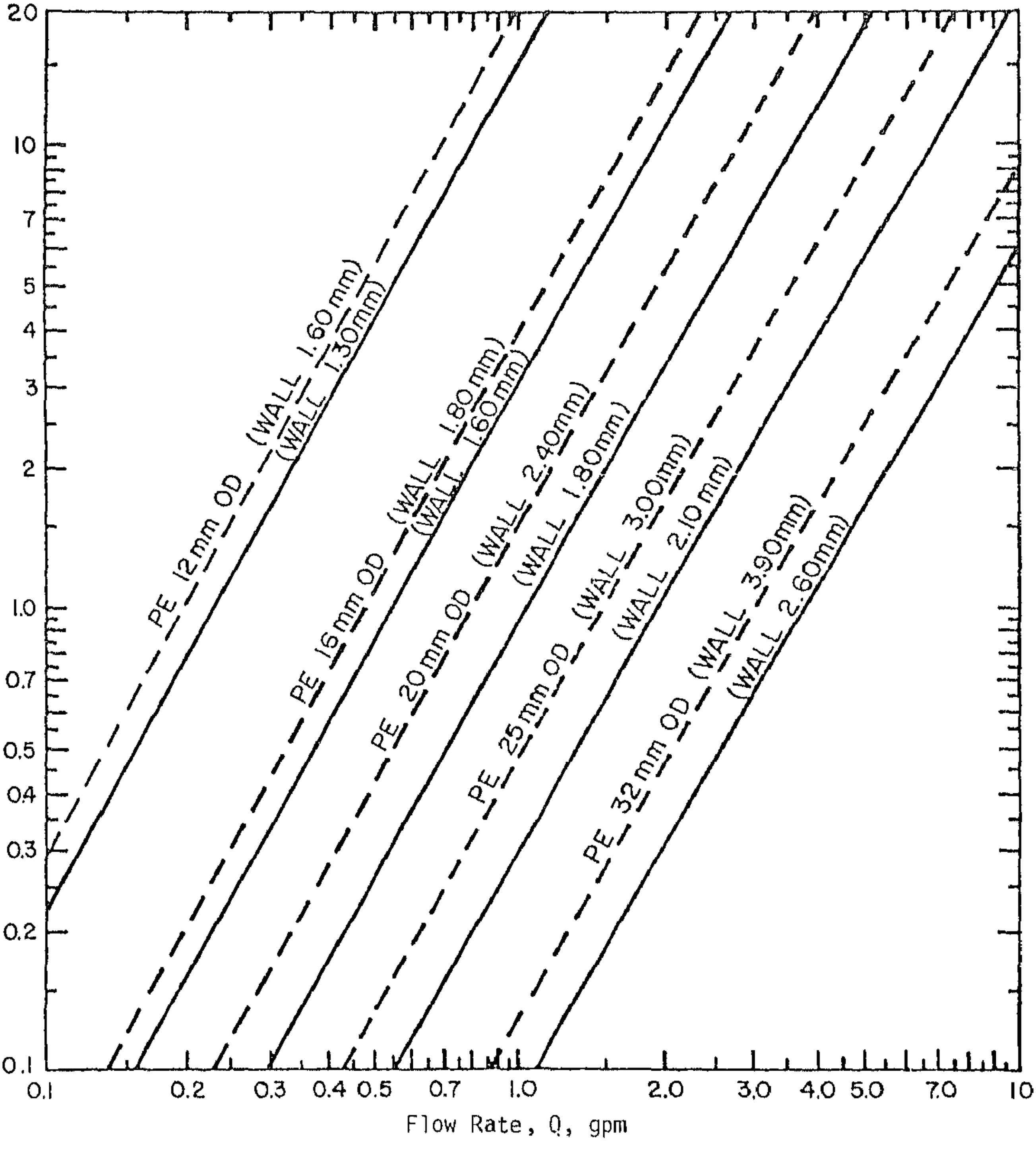


Exhibit C-4. Friction head loss as a function of flow rate for lateral tubing manufactured in metric dimensions.

FRICTION HEAD LOSS AND VELOCITY IN 0.580 and 0.622
(For Drip Irrigation Laterals)

H_f in PSI Per 100 Feet; V in Feet Per Second
Accumulated Head Loss Based on 1-GPH Emitters Spaced 5 Feet On Line
Table Based on Hazen-Williams Equation - C = 130

Q GPH	Q GPM	I.D. - 0.580" H_f	I.D. - 0.580" V	I.D. - 0.580" Accum. H_f	I.D. - 0.622" H_f	I.D. - 0.622" V	I.D. - 0.622" Accum. H_f	Line Length Ft
1	.017	.0004	.02		.0003	.02		5
2	.033	.0015	.04	.0001	.001	.03		10
3	.050	.003	.06	.0002	.002	.05	.00015	15
4	.067	.005	.08	.0005	.004	.07	.0004	20
5	.083	.008	.10	.0009	.006	.09	.0007	25
6	.100	.011	.12	.0015	.008	.11	.0011	30
7	.117	.015	.14	.002	.011	.12	.0015	35
8	.133	.019	.16	.003	.013	.14	.002	40
9	.150	.024	.18	.004	.017	.16	.003	45
10	.167	.029	.20	.006	.020	.18	.004	50
11	.183	.034	.22	.007	.024	.19	.005	55
12	.200	.040	.24	.009	.028	.21	.007	60
13	.217	.047	.26	.012	.033	.23	.008	65
14	.233	.053	.28	.014	.038	.25	.010	70
15	.250	.060	.30	.017	.043	.26	.012	75
16	.267	.068	.32	.021	.049	.28	.015	80
17	.283	.076	.34	.025	.054	.30	.017	85
18	.300	.085	.36	.029	.060	.32	.020	90
19	.317	.094	.38	.034	.067	.33	.024	95
20	.333	.10	.40	.038	.073	.35	.027	100
21	.350	.11	.42	.04	.080	.37	.03	105
22	.367	.12	.45	.05	.088	.39	.04	110
23	.383	.13	.46	.06	.095	.40	.04	115
24	.400	.14	.49	.06	.10	.42	.04	120
25	.417	.16	.51	.07	.11	.44	.05	125
26	.433	.17	.53	.08	.12	.46	.06	130
27	.450	.18	.55	.09	.13	.47	.06	135
28	.467	.19	.57	.10	.14	.49	.07	140
29	.483	.20	.59	.11	.15	.51	.08	145
30	.500	.22	.61	.12	.16	.53	.09	150

Table C-15 (con't)

FRICTION HEAD LOSS AND VELOCITY IN 0.580" and 0.622" PLASTIC HOSE
(For Drip Irrigation Laterals)

H_f in PSI Per 100 Feet; V in Feet Per Second
Accumulated Head Loss Based on 1-GPH Emitters Spaced 5 Feet On Line
Table Based on Hazen-Williams Equation - C = 130

Q GPH	Q GPM	I.D. - 0.580" H_f	I.D. - 0.580" V	I.D. - 0.580" Accum. H_f	I.D. - 0.622" H_f	I.D. - 0.622" V	I.D. - 0.622" Accum. H_f	Line Length Ft
31	.517	.23	.63	.13	.17	.55	.09	155
32	.533	.25	.65	.14	.17	.56	.10	160
33	.550	.26	.67	.16	.19	.58	.11	165
34	.567	.28	.69	.17	.20	.60	.12	170
35	.583	.29	.71	.19	.21	.62	.13	175
36	.600	.31	.73	.20	.22	.63	.14	180
37	.617	.32	.75	.22	.23	.65	.16	185
38	.633	.34	.77	.23	.24	.67	.17	190
39	.650	.35	.79	.25	.25	.69	.18	195
40	.667	.37	.81	.27	.26	.70	.19	200
41	.683	.39	.83	.29	.28	.72	.21	205
42	.700	.41	.85	.31	.29	.74	.22	210
43	.717	.43	.87	.33	.30	.76	.24	215
44	.733	.44	.89	.35	.31	.77	.25	220
45	.750	.46	.91	.38	.33	.79	.27	225
46	.767	.48	.93	.40	.34	.81	.29	230
47	.783	.50	.95	.43	.36	.83	.30	235
48	.800	.52	.97	.45	.37	.84	.32	240
49	.817	.54	.99	.48	.38	.86	.34	245
50	.833	.56	1.01	.51	.40	.88	.36	250
51	.850	.58	1.03	.54	.41	.90	.38	255
52	.867	.60	1.05	.57	.43	.91	.40	260
53	.883	.62	1.07	.60	.44	.93	.43	265
54	.900	.65	1.09	.63	.46	.95	.45	270
55	.917	.67	1.11	.66	.48	.97	.47	275
56	.933	.69	1.13	.70	.49	.98	.50	280
57	.950	.71	1.15	.73	.51	1.00	.52	285
58	.967	.74	1.17	.77	.53	1.02	.55	290
59	.983	.76	1.19	.81	.54	1.04	.58	295
60	1.000	.79	1.21	.85	.56	1.06	.60	300

FRICTION HEAD LOSS AND VELOCITY IN 0.580" and 0.622" PLASTIC HOSE
(For Drip Irrigation Laterals)

H_f in PSI Per 100 Feet; V in Feet Per Second
:cumulated Head Loss Based on 1-GPH Emitters Spaced 5 Feet On Line
Table Based on Hazen-Williams Equation - C = 130

Q	Q	I.D. - 0.580"			I. D. - 0.622"			Line Length
PH	GPM	H_f	V	Accum. H_f	H_f	V	Accum. H_f	Ft
1	1.017	.81	1.23	.89	.58	1.07	.63	305
2	1.033	.83	1.25	.93	.59	1.09	.66	310
3	1.050	.86	1.27	.97	.61	1.11	.69	315
4	1.067	.89	1.29	1.02	.63	1.13	.72	320
5	1.083	.91	1.31	1.06	.65	1.14	.76	325
6	1.100	.94	1.33	1.11	.67	1.16	.79	330
7	1.117	.96	1.35	1.16	.69	1.18	.82	335
8	1.133	.99	1.37	1.21	.70	1.20	.86	340
9	1.150	1.02	1.40	1.26	.72	1.21	.90	345
0	1.167	1.05	1.42	1.31	.74	1.23	.93	350
1	1.183	1.07	1.44	1.36	.76	1.25	.97	355
2	1.200	1.10	1.46	1.42	.78	1.27	1.01	360
3	1.217	1.13	1.48	1.47	.80	1.28	1.05	365
4	1.233	1.16	1.50	1.53	.82	1.30	1.09	370
5	1.250	1.19	1.52	1.59	.85	1.32	1.13	375
6	1.267	1.22	1.54	1.65	.87	1.34	1.18	380
7	1.283	1.25	1.56	1.72	.89	1.35	1.22	385
8	1.300	1.28	1.58	1.78	.91	1.37	1.27	390
9	1.317	1.31	1.60	1.85	.93	1.39	1.31	395
30	1.333	1.34	1.62	1.91	.95	1.41	1.36	400
	1.350	1.37	1.64	1.98	.97	1.42	1.41	405
	1.367	1.40	1.66	2.05	1.00	1.44	1.46	410
			1.68	2.12	1.02	1.46	1.51	415
			1.70	2.20	1.04	1.48	1.56	420
			1.72	2.27	1.07	1.49	1.62	425
36	1.433	1.53	1.74	2.35	1.09	1.51	1.67	430
37	1.450	1.56	1.76	2.42	1.11	1.53	1.73	435
38	1.467	1.60	1.78	2.50	1.14	1.55	1.78	440
39	1.483	1.63	1.80	2.59	1.16	1.56	1.84	445
90	1.500	1.66	1.82	2.67	1.18	1.58	1.90	450

FRICTION HEAD LOSS AND VELOCITY IN 0.580" and 0.622" PLASTIC HOSE
(For Drip Irrigation Laterals)

H_f in PSI Per 100 Feet; V in Feet Per Second
Accumulated Head Loss Based on 1-GPH Emitters Spaced 5 Feet On Line
Table Based on Hazen-Williams Equation - C = 130

Q	Q	I.D. - 0.580"			I.D. - 0.622"			Line Length Ft.
GPH	GPM	H_f	V	Accum. H_f	H_f	V	Accum. H_f	
91	1.517	1.70	1.84	2.75	1.21	1.60	1.96	455
92	1.533	1.73	1.86	2.84	1.23	1.62	2.02	460
93	1.550	1.77	1.88	2.93	1.26	1.64	2.08	465
94	1.567	1.80	1.90	3.02	1.28	1.65	2.15	470
95	1.583	1.84	1.92	3.11	1.31	1.67	2.21	475
96	1.600	1.87	1.94	3.20	1.33	1.69	2.28	480
97	1.617	1.91	1.96	3.30	1.36	1.71	2.35	485
98	1.633	1.95	1.98	3.40	1.39	1.72	2.42	490
99	1.650	1.98	2.00	3.50	1.41	1.74	2.49	495
100	1.667	2.02	2.02	3.60	1.44	1.76	2.56	500
101	1.683	2.06	2.04	3.70	1.46	1.78	2.63	505
102	1.700	2.10	2.06	3.81	1.49	1.79	2.71	510
103	1.717	2.14	2.08	3.91	1.52	1.81	2.78	515
104	1.733	2.17	2.10	4.02	1.55	1.83	2.86	520
105	1.750	2.21	2.12	4.13	1.57	1.85	2.94	525
106	1.767	2.25	2.14	4.24	1.60	1.86	3.02	530
107	1.783	2.29	2.16	4.36	1.63	1.88	3.10	535
108	1.800	2.33	2.18	4.48	1.66	1.90	3.18	540
109	1.817	2.37	2.20	4.59	1.69	1.92	3.27	545
110	1.833	2.41	2.22	4.71	1.72	1.93	3.36	550
111	1.850	2.45	2.24	4.84	1.75	1.95	3.44	555
112	1.867	2.49	2.26	4.96	1.77	1.97	3.53	560
113	1.883	2.53	2.28	5.09	1.80	1.99	3.62	565
114	1.900	2.58	2.30	5.22	1.83	2.00	3.71	570
115	1.917	2.62	2.33	5.35	1.86	2.02	3.81	575
116	1.933	2.66	2.35	5.48	1.89	2.04	3.90	580
117	1.950	2.70	2.37	5.62	1.92	2.06	4.00	585
118	1.967	2.75	2.39	5.75	1.95	2.08	4.09	590
119	1.983	2.79	2.41	5.89	1.98	2.09	4.19	595
120	2.000	2.83	2.43	6.03	2.02	2.11	4.29	600

FRICTION HEAD LOSS AND VELOCITY IN 0.580" and 0.622" PLASTIC HOSE
(For Drip Irrigation Laterals)

H_f in PSI Per 100 Feet; V in Feet Per Second
Accumulated Head Loss Based on 1-GPH Emitters Spaced 5 Feet On Line
Table Based on Hazen-Williams Equation - C = 130

Q	Q	I.D. - 0.580"			I.D. - 0.622"			Line Length
GPH	GPM	H_f	V	Accum. H_f	H_f	V	Accum. H_f	Ft
121	2.017	2.88	2.45	6.18	2.05	2.13	4.40	605
122	2.033	2.92	2.47	6.32	2.08	2.14	4.50	610
123	2.050	2.97	2.49	6.47	2.11	2.16	4.61	615
124	2.067	3.01	2.51	6.62	2.14	2.18	4.71	620
125	2.083	3.05	2.53	6.78	2.17	2.20	4.82	625
126	2.100	3.10	2.55	6.93	2.21	2.22	4.93	630
127	2.117	3.15	2.57	7.09	2.24	2.23	5.04	635
128	2.133	3.19	2.59	7.25	2.27	2.25	5.16	640
129	2.150	3.24	2.61	7.41	2.30	2.27	5.27	645
130	2.167	3.29	2.63	7.57	2.34	2.29	5.39	650
131	2.183	3.33	2.65	7.74	2.37	2.30	5.51	655
132	2.200	3.38	2.67	7.91	2.40	2.32	5.63	660
133	2.217	3.43	2.69	8.08	2.44	2.34	5.75	665
134	2.233	3.47	2.71	8.25	2.47	2.36	5.87	670
135	2.250	3.52	2.73	8.43	2.51	2.37	6.00	675
136	2.267	3.57	2.75	8.61	2.54	2.39	6.13	680
137	2.283	3.62	2.77	8.79	2.58	2.41	6.25	685
138	2.300	3.67	2.79	8.97	2.61	2.43	6.39	690
139	2.317	3.72	2.81	9.16	2.65	2.44	6.52	695
140	2.333	3.77	2.83	9.35	2.68	2.46	6.65	700
	2.350	3.82	2.85	9.54	2.72	2.48	6.79	705
	2.367	3.87	2.87	9.73	2.75	2.50	6.93	710
	[illegible]	3.92	2.89	9.93	2.79	2.51	7.06	715
		[illegible]	2.91	10.13	2.82	2.53	7.21	720
			2.93	10.33	2.86	2.55	7.35	725
				10.53	2.90	2.57	7.49	730
				10.74	2.93	2.58	7.64	735
				10.95	2.97	2.60	7.79	740
				1.16	3.01	2.62	7.94	745
				1.37	3.05	2.64	8.09	750

TABLE C-16

PRESSURE LOSS IN CENTER-PIVOT SYSTEM, psi

System Length	Pipe Size	"Q" gpm at Pivot									
		300	400	500	600	700	800	900	1000	1100	1200
600	4" 5"	11 3.5	18 6	27 9							
700	5" 6"	4.0 1.7	7 3	11 4.5	15 6						
800	5" 6"	4.5 2.0	8 3.5	12 5	18 7	24 10					
900	5" 6" 6½"	5.0 2.3 --	9 4.0 --	14 6 --	20 8 --	27 11 7	34 14 10				
1000	5" 6" 6½"	5.5 2.6 --	10 4.5 --	16 6.5 --	23 9 --	30 12 8	38 15 11	-- 19 14			
1100	5" 6" 6½"	6.0 3.0 --	11 5 --	17 7 --	25 10 6	33 13 9	42 17 12	-- 21 15	-- 26 18		
1200	5" 6" 6½"		12 5.5 3.5	19 7.5 5.0	27 11 7	36 15 10	-- 19 13	-- 23 16	-- 28 19	-- 35 23	
1300	6" 6½" 7"			8 5.5 --	12 8 5	16 11 7	20 14 9	25 17 12	31 21 15	37 25 18	45 30 22
1400	6" 6½" 7"				13 9 6	17 12 8	22 15 10	27 19 13	33 23 16	40 27 19	48 32 23
1500	6" 6½" 7"					18 13 9	23 16 11	29 20 14	35 24 17	42 28 20	51 34 24
1600	6" 6½" 7"						25 17 12	31 21 15	37 26 18	45 30 21	54 [illegible]
1700	6" 6½" 7"							33 23 16	39 27 19	47 32 22	
1800	6" 6½" 7"								41 29 20	50 34 23	

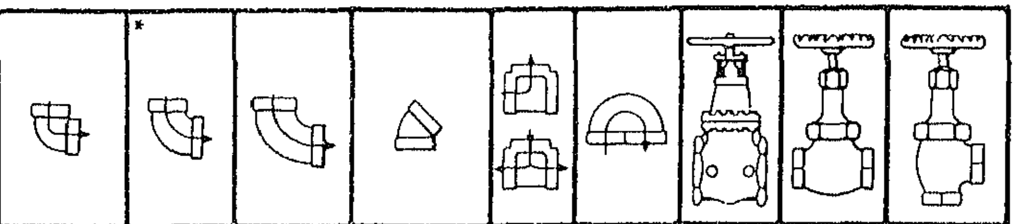
FACTORS (F) FOR COMPUTING FRICTION HEAD
LOSS IN A LINE WITH MULTIPLE OUTLETS

		No Outlets	F		No Outlets	F		
		1	1.000		24	.372		
		2	.639		25	.371		
		3	.534		26	.370		
		4	.485		28	.369		
		5	.457		30	.368		
		6	.438		32	.367		
		7	.425		34	.366		
		8	.416		36	.365		
		9	.408		38	.364		
		10	.402		40	.363		
		11	.398		45	.362		
		12	.394		50	.361		
		13	.390		55	.360		
		14	.387		60	.359		
		15	.385		70	.358		
		16	.383		80	.357		
		17	.381		90	.356		
		18	.379		100	.356		
		19	.378		110	.355		
		20	.376		120	.355		
		21	.375		130	.355		
		22	.374		140	.355		
		23	.373		150	.355		

Table C-18. Head Loss Coefficients for Fittings and Special Conditions Where $H = \frac{Kv^2}{2g}$

Nature of Resistance	Typical Value K	Remarks
Check Valve	3.0 - 10.0	-
Elbows		
45°	0.4	-
90°	0.65	-
Entrance		
Square	0.5	-
Projecting	0.78	-
Rounded	0.05	-
Gate Valve, Open	0.25	-
Globe Valve, Open	6.0	-
Sudden Contraction	0.4	v = velocity of smaller pipe
Sudden Enlargement	$1-\frac{d_1^2}{d_2^2}$	d_1 & d_2 = diameter of small and large pipe respectively
Taper Reducer	0.25	v = velocity of smaller pipe
Taper Increaser	0.15	v = velocity of smaller pipe
Tees or Crosses		
Straight flow	0.10	-
Angle flow	1.50	-
Angle Valve	5.0	-
Foot Valve	0.8	
Strainers - basket type		
3 inch dia. ---------	1.25	
4 inch dia. ---------	1.05	
5 inch dia. ---------	.95	
6 inch dia. ---------	.85	
7 inch dia. ---------	.80	
8 inch dia. ---------	.75	

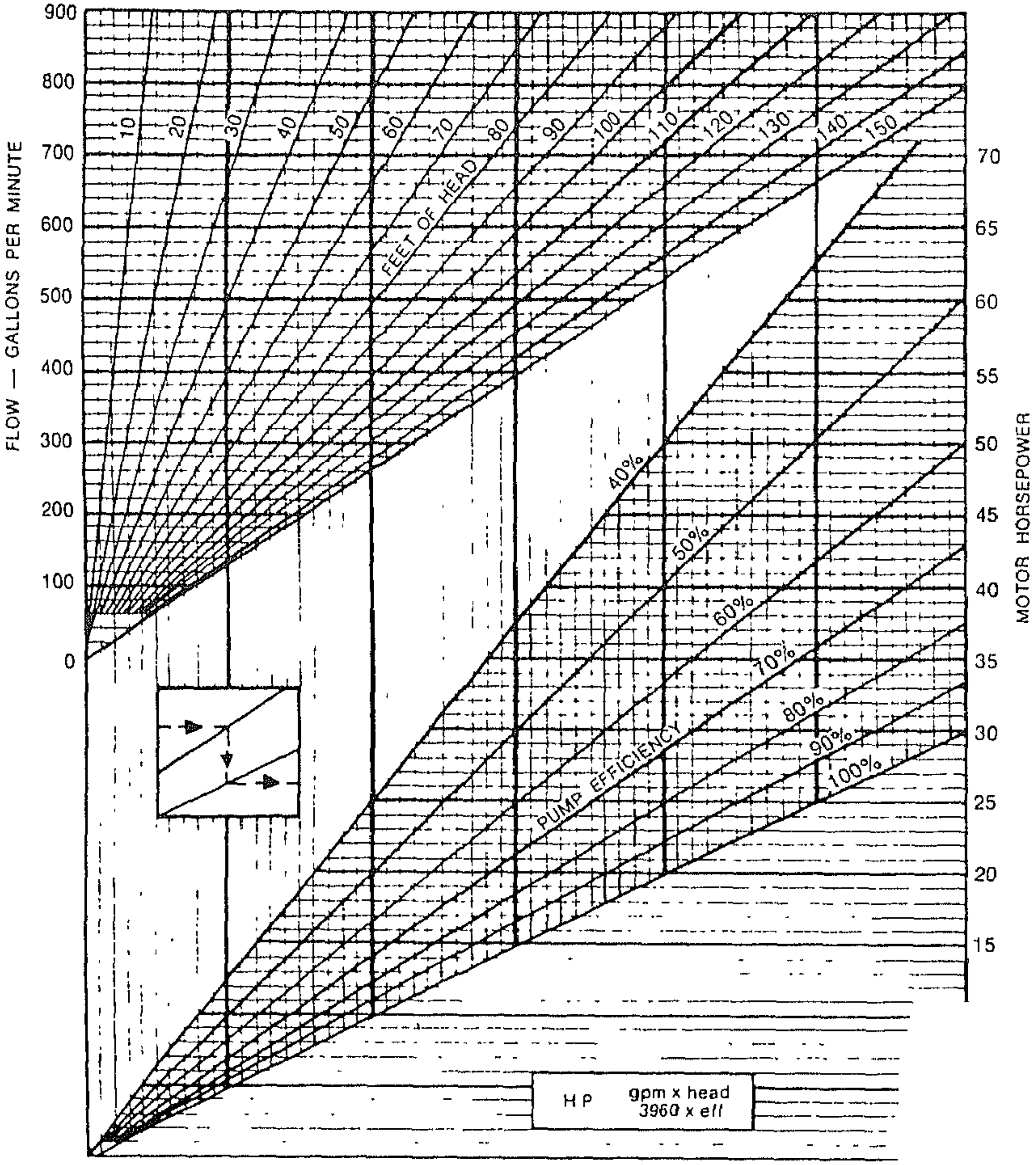
FRICTION LOSSES THROUGH PIPE FITTINGS IN TERMS OF EQUIVALENT LENGTHS OF STANDARD PIPE



Size of Pipe (Small Dia.) (Inches)	Standard Elbow	* Medium Radius Elbow	Long Radius Elbow	45° Elbow	Tee	Return Bend	Gate Valve Open	Globe Valve Open	Angle Valve Open
Length of Straight Pipe Giving Equivalent Resistance Flow – ft									
1/2	1.5	1.4	1.1	0.77	3.4	3.8	0.35	16	8.4
3/4	2.2	1.8	1.4	1.0	4.5	5.0	0.47	22	12.0
1	2.7	2.3	1.7	1.3	5.8	6.1	0.6	27	15.0
1-1/4	3.7	3.0	2.4	1.6	7.8	8.5	0.8	37	18.0
1-1/2	4.3	3.6	2.8	2.0	9.0	10.0	0.95	44	22.0
2	5.5	4.6	3.5	2.5	11.0	13.0	1.2	57	28.0
2-1/2	6.5	5.4	4.2	3.0	14.0	15.0	1.4	66	33.0
3	8.1	6.8	5.1	3.8	17.0	18.0	1.7	85	42.0
3-1/2	9.5	8.0	6.0	4.4	19.0	21.0	2.0	99	50.0
4	11.0	9.1	7.0	5.0	22.0	24.0	2.3	110	58.0
4 1/2	12.0	10.0	7.0	5.6	24.0	27.0	2.6	130	61.0
5	14.0	12.0	8.9	6.1	27.0	31.0	2.9	140	70.0
6	16.0	14.0	11.0	7.7	33.0	37.0	3.5	160	83.0
8	21.0	18.0	14.0	10.0	43.0	49.0	4.5	220	110.0
	26.0	22.0	17.0	13.0	56.0	61.0	5.7	290	140

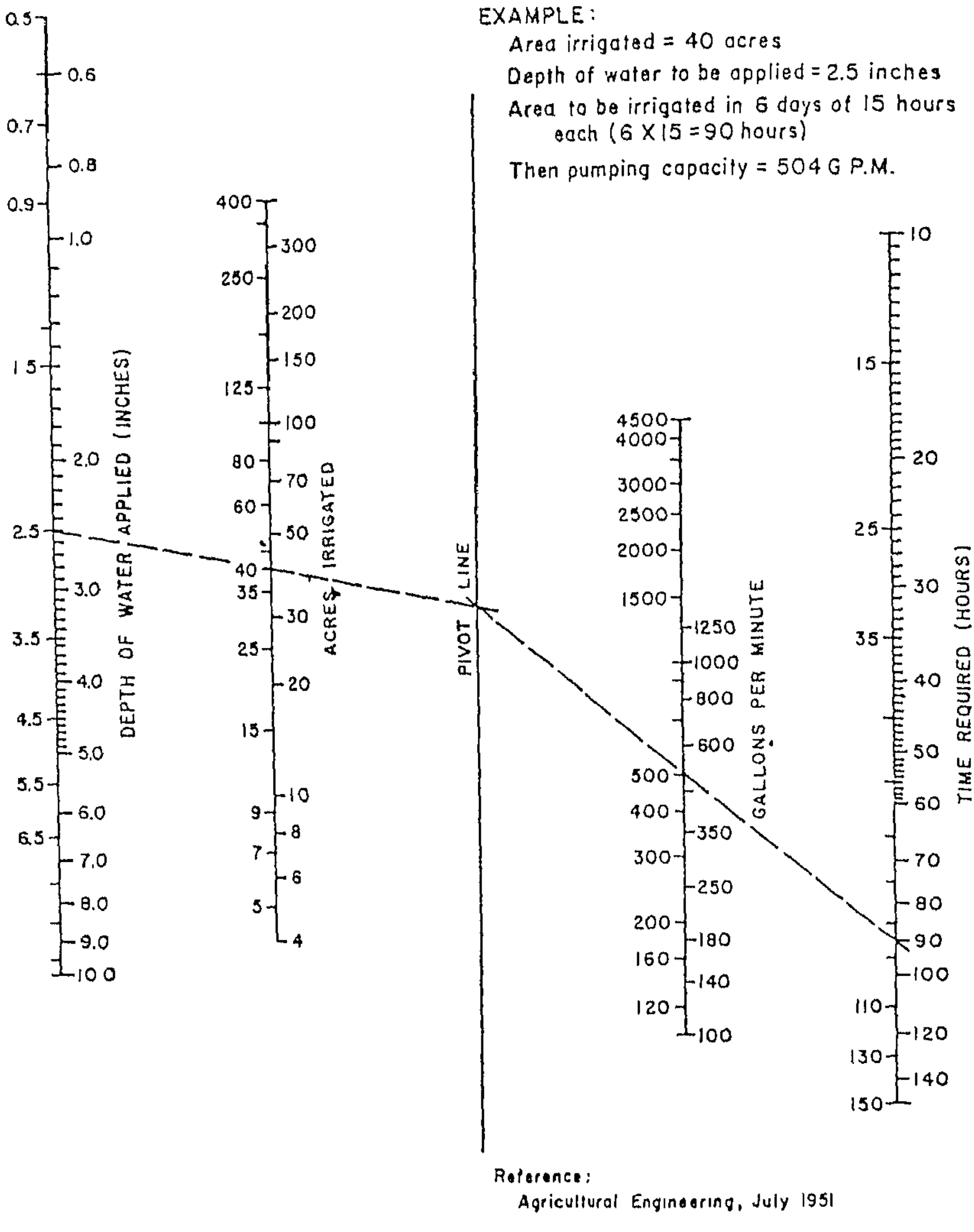
Exhibit C-5

HORSEPOWER REQUIRED TO PUMP WATER



TO USE CHART: Start at value of flow and move horizontally to line of required pump head Fro vertically downward to line of known or expected pump efficiency From this point move horizontal read value of required motor horsepower Next refer to Figure 20 and select standard motor size than value obtained from the chart

Number of days (F) X Hours per day (H)



Capacity Requirements For Irrigation Systems.

Table C-20

APPLICATION RATE FOR PLANNING IRRIGATION SYSTEMS (Inches Per Hour)

Sprinkler Spacing(ft.)	Gallons Per Minute from each Sprinkler																	
	1	2	3	4	5	6	8	10	12	15	18	20	25	30	35	40	45	50
20x20	.24	.48	.72	.96	1.20	1.44	1.92											
20x30	.16	.32	.48	.64	.80	.96	1.28	1.60	1.93									
20x40	.12	.24	.36	.48	.60	.72	.96	1.20	1.45	1.81	2.17							
20x50	.10	.20	.30	.40	.50	.60	.80	1.00	1.20	1.50	1.80	2.00						
20x60	.08	.16	.24	.32	.40	.48	.64	.80	.96	1.20	1.44	1.60	2.00					
25x25	.15	.30	.46	.61	.77	.92	1.23	1.54	1.85	2.31								
30x30	.11	.21	.32	.43	.54	.64	.86	1.07	1.28	1.61	1.93	2.14						
30x40		.16	.24	.32	.40	.48	.64	.80	.96	1.20	1.45	1.61	2.01	2.40				
30x50		.13	.19	.25	.32	.38	.51	.64	.76	.96	1.15	1.28	1.60	1.92				
30x60		.11	.16	.21	.27	.32	.43	.53	.64	.80	.96	1.07	1.54	1.61	1.87	2.14		
40x40		.12	.18	.24	.30	.36	.48	.60	.72	.90	1.08	1.20	1.50	1.80	2.10	2.40		
40x50		.10	.14	.19	.24	.29	.38	.48	.58	.72	.86	.96	1.20	1.44	1.68	1.92	2.16	
40x60			.12	.16	.20	.24	.32	.40	.48	.60	.72	.80	1.00	1.20	1.40	1.60	1.80	2.00
40x80			.09	.12	.15	.18	.24	.30	.36	.45	.54	.60	.75	.90	1.05	1.20	1.35	1.50
50x50			.12	.15	.19	.23	.31	.39	.46	.58	.69	.77	.96	1.15	1.35	1.54	1.73	1.92
50x60			.10	.13	.16	.19	.26	.32	.39	.48	.58	.64	.80	.96	1.12	1.28	1.44	1.60
50x70				.11	.14	.17	.22	.28	.33	.41	.49	.55	.69	.82	.96	1.10	1.24	1.37
60x60				.11	.13	.16	.21	.27	.32	.40	.48	.53	.67	.80	.93	1.07	1.20	1.34
60x70					.11	.14	.18	.23	.27	.34	.41	.46	.57	.69	.80	.92	1.03	1.15
60x80					.10	.12	.16	.20	.24	.30	.36	.40	.50	.60	.70	.80	.90	1.00
70x70					.10	.12	.16	.20	.24	.29	.35	.39	.49	.59	.69	.79	.88	.98
70x80						.10	.14	.17	.21	.26	.31	.34	.43	.52	.60	.69	.77	.86
70x90							.12	.15	.18	.23	.28	.30	.37	.46	.53	.61	.69	.76
80x80							.12	.15	.18	.23	.27	.30	.38	.45	.53	.60	.68	.75
80x90							.11	.13	.16	.20	.24	.27	.33	.40	.47	.53	.60	.67
80x100							.10	.12	.14	.18	.22	.24	.30	.36	.42	.48	.54	.60
100x100								.10	.12	.14	.17	.19	.24	.29	.34	.39	.43	.48

Table C-21

CENTER PIVOT SYSTEMS

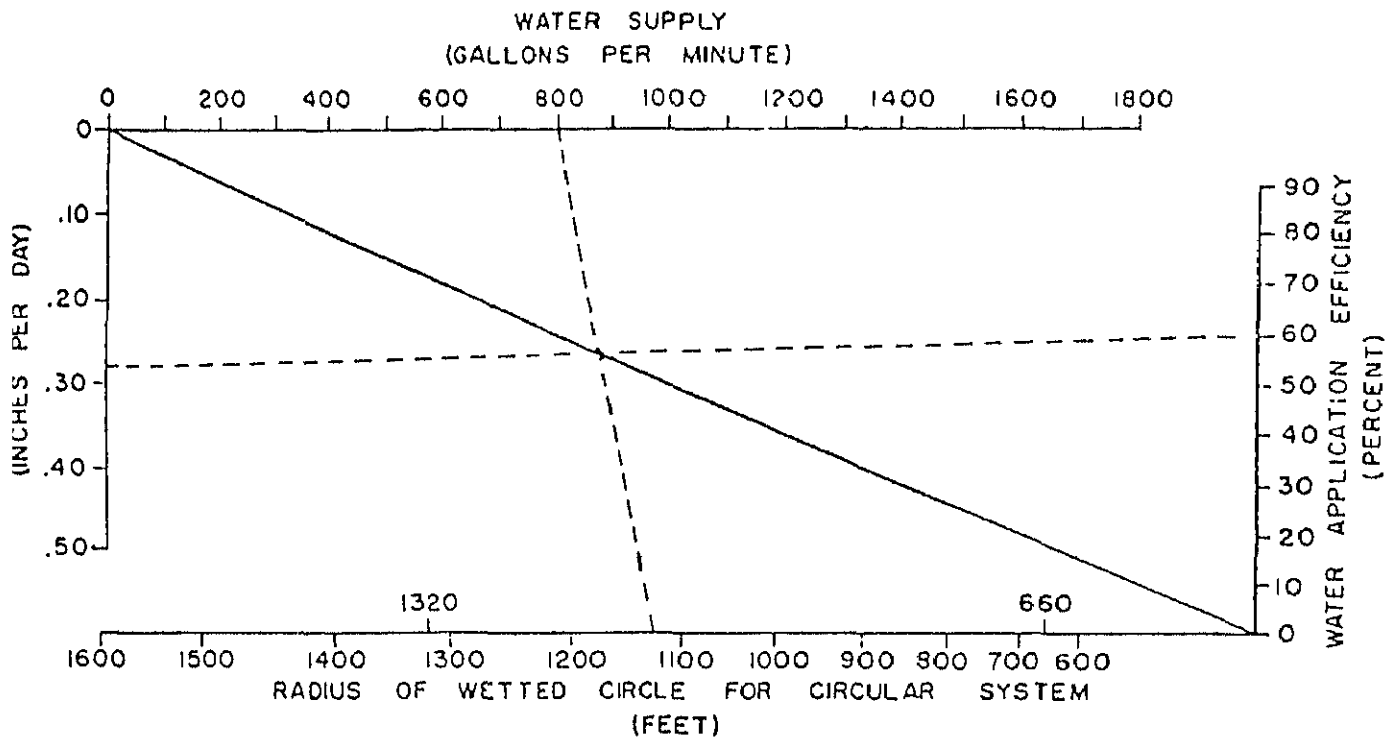
TIME REQUIRED TO APPLY 1" GROSS APPLICATION (hrs/in.)
AND GROSS CAPACITY (in./day)

Total Lateral Length	Area * Covered (acres)	Hours Per 1" Application (Col. 1) Gross Capacity in in./day (Col. 2)									
		400 gpm		600 gpm		800 gpm		1000 gpm		1200 gpm	
		hrs/ in.	in./ day	hrs/ in.	in./ day	hrs/ in.	in./ day	hrs/ in.	in./ day	hrs/ in.	in./ day
500	26	29.2	.82	19.5	1.23	14.6	1.65	11.7	2.06	9.8	2.44
550	30.5	34.4	.70	23.0	1.04	17.2	1.4	13.7	1.75	11.4	2.10
600	35.3	38.7	.62	26.4	.91	19.8	1.2	15.9	1.51	13.2	1.82
650	40.6	45.6	.52	30.4	.79	22.9	1.05	18.2	1.32	15.2	1.58
700	52.1	58.6	.41	39.0	.61	29.4	.82	23.4	1.02	19.5	1.23
800	58.4	66.1	.36	44.0	.54	32.8	.73	26.3	.91	21.9	1.09
850	65.0	73.0	.33	48.7	.49	36.6	.65	29.3	.82	24.3	.99
900	72.2	81.2	.29	54.2	.44	40.6	.59	32.5	.74	27.1	.89
950	79.5	89.2	.27	59.5	.40	44.8	.53	35.8	.67	29.8	.81
1000	87.4	98.3	.24	65.5	.37	49.2	.49	39.4	.61	32.8	.73
1050	95.3	107	.22	71.5	.33	53.6	.45	42.9	.56	35.7	.67
1100	104.0	117	.20	78.0	.31	58.5	.41	46.8	.51	39.0	.61
1150	112.6	126	.19	84	.29	63.4	.38	50.7	.47	42.2	.57
1200	121.9	137	.17	91.5	.26	68.6	.35	54.9	.44	45.6	.52
1250	130.0	146	.16	97.5	.25	73.1	.33	58.5	.41	48.7	.49
			.15	106	.23	79.5	.30	63.6	.38	53.0	.45
			14	113	.21	85.5	.28	68.3	.35	56.7	.42
			13	122	.20	91.2	.26	73.0	.33	60.7	.40
			12	130	.18	97.5	.25	78.0	.31	65.0	.37
			11	138	.17	104	.23	83.0	.29	69.2	.35

re circle.

Exhibit C-7

Center Pivot Water Supply Nomograph



The nomograph above can be used to calculate water supply requirements for self-propelled center pivot sprinkler systems. Its use is explained by the following examples.

Example 1:
Given: Water supply, 800 gpm; plant water use rate, 0.28" per day; water application efficiency, 60%. What is the radius of the circle that this system will adequately irrigate?

Solution: Locate 0.28" on the "Water Use Rate" scale and 60 on the application efficiency scale. Connect the two points by using a straightedge and note the point of intersection on the solid diagonal line. Locate 800 gpm on the upper scale labeled "Water Supply"; connect this point with the point located on the diagonal line and project this line to the lower scale labeled "Radius of Wetted Circle." This point reads slightly more than 1,100' - the maximum radius of the wetted circle that 800 gpm will properly irrigate.

Example 2:
Given: Desired radius of wetted circle, 1,320'; water use rate 0.20" per day; application efficiency, 60%. What is the required water supply?

Solution: Locate 1320 on the lower scale, then draw a line from this point through the intersection point on the diagonal and extend it on to the upper scale labeled "Water Supply." The point on the upper scale is between 1,100 and 1,150 gpm. A water supply of 1,125 gpm is required to adequately irrigate a circle this size under the given conditions. It is obvious that an increase in water application efficiency will reduce the total water requirements.

Table C-22

STANDARD PIPE DIMENSIONS

ALL DIMENSIONS IN INCHES

RIGID PVC PLASTIC PIPE

Nominal Pipe Diameter-Inch	Outside Dia	CL 100 SDR 41		CL 125 SDR 32 5		CL 160 SDR 26		CL 200 SDR 21		CL 315 SDR 13.5		SCH 40 Plastic		SCH 80 Plastic	
		ID	WALL	ID	WALL	ID	WALL	ID	WALL	ID	WALL	ID	WALL	ID	WALL
1/2	840									716	062	.622	109	.546	.147
3/4	1 050							.930	060	.894	.078	.824	.113	.742	.154
1	1 315					1.195	.060	1 189	.063	1.121	.097	1.049	.133	.957	.179
1-1/4	1.660					1 532	.064	1.502	079	1 414	123	1 380	.140	1.278	.191
1-1/2	1.900					1.754	073	1,720	090	1.618	141	1.610	.145	1 500	.200
2	2 375					2.193	.091	2 149	113	2 023	.176	2.067	154	1.939	.218
2 1/2	2.875					2 655	.110	2 601	.137	2.449	213	2.469	.203	2.323	.276
3	3 500			3.284	.108	3 230	135	3 166	167	2 982	.259	3 068	216	2.900	.300
4	4.500	4 280	110	4 224	138	4 154	173	4.072	214	3.834	.333	4.026	.237	3.826	.337
6	6.625	6.301	.162	6.217	204	6.115	.255	5 993	.316	5 643	491	6.065	.280	5.761	.432
8	8.625	8 205	210	8.095	265	7.961	.332	7.805	.410						
10	10 750	10.226	.262	10.088	.331	9 924	.413	9.728	511						
12	12 750	12.128	.311	11 966	.392	11.770	.490	11.538	606						

Table C-23

STANDARD PIPE DIMENSIONS

FLEXIBLE POLYETHYLENE TUBE (PE)

Nominal Pipe Size Inch	Inside Dia. Inch	SDR 15-80 PSI Wall Thickness Inch	SDR 11.5 100 PSI Wall Thickness Inch	SDR 9 125 PSI Wall Thickness Inch	SDR 7 125 PSI Wall Thickness Inch
1/2	0.622	0.060	0.060	0.069	0.089
3/4	0.824	0.060	0.072	0.092	0.118
1	1.049	0.070	0.091	0.117	0.150
1-1/4	1.380	0.092	0.120	0.153	0.197
1-1/2	1.610	0.107	0.140	0.179	0.230
2	2.067	0.138	0.180	0.230	0.297
2-1/2	2 469	0.165	0 215		
3	3.068	0.205	0.267		
4	4.026	0.268	0.350		
6	6.065	0.404	0.527		

Table C-24

STANDARD PIPE DIMENSION

ALL DIMENSIONS IN INCHES

ASBESTOS - CEMENT IRRIGATION PIPE

Nominal Pipe Size - Inches	Inside Diameter	Type 25 Outside Dia.	Type 75 Outside Dia.	Type 125 Outside Dia.	Class 100 Outside Dia.	Class 150 Outside Dia.	Class 200 Outside Dia.
3	3.00	4.00	4.00	4.06	4.06	4.03	4.20
4	4.00	5.06	5.06	5.08	5.08	5.15	5.31
5	5.00	5.92	5.92				
6	6.00	6.90	6.90	7.17	7.17	7.13	7.35
8	8.00	9.06	9.06	9.38	9.33	9.45	9.69
10	10.00	11.15	11.15	11.40	11.45	11.85	11.89
12	12.00	13 25	13.25	13.58	13.70	14.12	14.12
14	14.00	15.31	15.31	15 35	15.36	16.40	16.44
15	15 00	16.45	16 45	17.04	17.03	17.91	18.46
16	16.00	17 49	17.49	17.48	17.50	18.65	18.75
18	18.00	19.61	19.61	20.29	20.45	21.21	
20	20.00	21.66	21.66	22.50	22.50	23.55	
21	21.00	22.75	22.75	23.72	24.00	24.94	
24	24.00	26.01	26.01	26.87	27.18	28.21	

Table C-25

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENSION RATIO - SDR = 26

For IPS Pipe

Q allons er min.	1-inch 1.195 ID	1¼-inch 1.540 ID	1½-inch 1.754 ID	2-inch 2.193 ID	2½-inch 2.655 ID	3-inch 3.230 ID	3½-inch 3.692 ID	Q Gallons per mi
	Friction Head Loss in Feet per Hundred Feet							
2	.14	.04	.02					2
4	.49	.15	.08	.03	.01			4
6	1.05	.34	.17	.05	.02			6
8	1.79	.57	.29	.10	.04	.01		8
10	2.71	.86	.45	.15	.05	.02	.01	10
15	5.75	1.85	.95	.32	.13	.05	.02	15
20	9.82	3.15	1.62	.55	.21	.08	.04	20
25	14.83	4.75	2.46	.83	.33	.12	.06	25
30	20.80	6.66	3.44	1.16	.46	.17	.09	30
35		8.87	4.58	1.55	.61	.23	.12	35
40		11.34	5.88	1.98	.78	.29	.15	40
45		14.11	7.30	2.47	.97	.36	.19	45
50		17.17	8.87	3.00	1.18	.45	.23	50
55		20.46	10.59	3.59	1.40	.54	.27	55
60			12.41	4.20	1.65	.63	.33	60
65			14.42	4.88	1.91	.73	.37	65
70			16.55	5.59	2.20	.84	.43	70
75			18.79	6.36	2.50	.96	.50	75
80			21.18	7.15	2.82	1.08	.56	80
85				8.02	3.16	1.21	.63	85
90				8.91	3.50	1.35	.70	90
95				9.85	3.87	1.49	.77	95
100				10.82	4.27	1.64	.85	100
110				12.93	5.09	1.95	1.01	110
120				15.19	5.97	2.29	1.19	120
130				17.61	6.94	2.66	1.39	130
140				20.21	7.94	3.06	1.59	140
150					9.05	3.48	1.81	150
160					10.19	3.90	2.04	160
170					11.38	4.37	2.28	170
180					12.65	4.87	2.54	180
190					14.00	5.39	2.80	190
200					15.39	5.92	3.08	200
220					18.38	7.07	3.68	220
240					21.59	8.30	4.33	240
260						9.62	[illegible]	[illegible]
280						11.02		
300						12.54		
320						14.12		
340						15.18		
360						17.54		
380						19.41		
400						21.34		
420								
440								
460								
480								
500								

Table based on Hazen-Williams equation - C_1 =150

Dashed line indicates 5 Ft/sec. velocity.

Table C-25

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENTION RATIO - SDR = 26

For IPS pipe

Q Gallons per min.	4-inch 4.154 ID	5-inch 5.135 ID	6-inch 6.115 ID	8-inch 7.961 ID	10-inch 9.924 ID	12-inch 11.770 ID	Q Gallons per min.
			Friction Head Loss in Feet per Hundred Feet				
15	.01						15
20	.02						20
25	.04	.01					25
30	.05	.02					30
35	.06	.02	.01				35
40	.08	.03	.01				40
45	.11	.04	.01				45
50	.13	.05	.02				50
55	.15	.05	.02				55
60	.18	.06	.03				60
65	.21	.07	.03	.01			65
70	.25	.08	.04	.01			70
75	.28	.10	.04	.01			75
80	.32	.11	.05	.01			80
85	.36	.13	.05	.01			85
90	.39	.14	.06	.01			90
95	.44	.15	.06	.02			95
100	.47	.17	.06	.02			100
110	.57	.20	.08	.02			110
120	.68	.24	.09	.03	.01		120
130	.77	.27	.11	.03	.01		130
140	.89	.32	.13	.04	.01		140
150	1.01	.36	.15	.05	.01		150
160	1.15	.40	.17	.05	.01		160
170	1.28	.45	.19	.05	.02		170
180	1.43	.50	.22	.06	.02	.01	180
190	1.57	.56	.24	.06	.02	.01	190
200	1.73	.61	.26	.07	.02	.01	200
220	2.07	.74	.31	.08	.03	.01	220
240	2.43	.86	.36	.09	.03	.01	240
260	2.82	1.00	.42	.11	.04	.02	260
280	3.24	1.15	.49	.13	.05	.02	280
[illegible]	[illegible]	[illegible]	.56	.15	.05	.02	300
			.63	.17	.05	.03	320
			.70	.19	.06	.03	340
			.78	.22	.07	.03	360
			.86	.24	.08	.04	380
			.95	.25	.09	.04	400
			1.04	.28	.09	.05	420
			1.14	.31	.10	.05	440
			1.23	.34	.11	.05	460
			1.33	.37	.13	.05	480
			1.44	.39	.14	.05	500
			1.72	.47	.16	.06	550
			2.02	.56	.19	.08	600

Table C-25

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENTION RATIO - SRS =26

For IPS Pipe

Q Gallons per min.	4-inch 4.154 ID	5-inch 5.135 ID	6-inch 6.115 ID	8-inch 7.961 ID	10-inch 9.924 ID	12-inch 11.770 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet						
600	13.30	4.74	2.02	.56	.19	.08	600
650	15.42	5.50	2.35	.65	.22	.09	650
700	17.70	6.30	2.69	.74	.25	.11	700
750	20.09	7.16	3.06	.85	.29	.13	750
800		8.08	3.44	.95	.33	.15	800
850		9.04	3.86	1.06	.36	.15	850
900		10.06	4.29	1.18	.40	.17	900
950		11.08	4.74	1.31	.45	.19	950
1000		12.19	5.23	1.44	.49	.21	1000
1050		13.35	5.71	1.57	.54	.24	1050
1100		14.56	6.22	1.71	.59	.25	1100
1150		15.82	6.74	1.87	.64	.27	1150
1200		17.11	7.30	2.01	.69	.30	1200
1250		18.45	7.88	2.17	.75	.32	1250
1300		19.82	8.48	2.34	.80	.34	1300
1350			9.09	2.51	.86	.36	1350
1400			9.70	2.68	.92	.39	1400
1450			10.37	2.88	.98	.43	1450
1500			11.04	2.05	1.05	[illegible]	1500
1600			12.45				
1700			13.91				
1800			15.46				

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPE
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENSION RATIO - SDR = 32.5

For IPS Pipe

Friction Head Loss in Feet per Hundred Feet

Q Gallons per min.	1¼-inch 1.540 ID	1½-inch 1.780 ID	2-inch 2.255 ID	2½-inch 2.709 ID	3-inch 3.184 ID	3½-inch 3.754 ID	Q Gallons per min.
2	.03	.02					2
4	.14	.08	.03	.01			4
6	.31	.16	.05	.02			6
8	.53	.27	.09	.03	.01		8
10	.80	.41	.13	.05	.02	.01	10
15	1.71	.87	.29	.12	.04	.02	15
20	2.91	1.50	.50	.19	.08	.03	20
25	4.38	2.27	.76	.30	.11	.06	25
30	6.15	3.18	1.07	.42	.16	.08	30
35	8.19	4.23	1.43	.56	.21	.11	35
40	10.47	5.43	1.83	.72	.27	.14	40
45	13.03	6.74	2.28	.90	.34	.18	45
50	15.85	8.19	2.79	1.09	.41	.21	50
55	18.88	9.78	3.31	1.29	.50	.25	55
60		11.46	3.88	1.52	.58	.30	60
65		13.31	4.50	1.76	.67	.34	65
70		15.28	5.16	2.03	.77	.39	70
75		17.35	5.87	2.31	.89	.46	75
80		19.56	6.60	2.60	1.00	.52	80
85			7.40	2.91	1.12	.58	85
90			8.22	3.23	1.24	.65	90
95			9.09	3.57	1.38	.71	95
100			9.99	3.94	1.51	.78	100
110			11.94	4.70	1.80	.93	110
120			14.02	5.51	2.12	1.10	120
130			16.25	6.41	2.45	1.29	130
140			18.66	7.33	2.82	1.47	140
150				8.35	3.21	1.67	150
160				9.41	3.60	1.88	160
170				10.51	4.03	2.10	170
180				11.68	4.49	2.34	180
190				12.93	4.97	2.59	190
200				14.20	5.46	2.84	200
220				16.96	6.53	3.39	220
240				19.93	7.66	4.00	240
					8.88	4.63	260
					10.17	5.31	280
					11.58	6.03	300
					13.04	6.80	320
					14.59	7.62	340
					16.19	8.47	360
					17.92	9.35	380
					19.70	10.26	400
						11.26	420
						12.26	440
						13.32	460
						14.41	480
						15.54	500

Table based on Hazen-Williams equation - C_1 = 150.

Dashed line indicates 5 Ft/sec velocity

Table C-26

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENSION RATIO - SDR = 32.5

For IPS Pipe

Friction Head Loss in Feet per Hundred Feet

Q Gallons per min.	4-inch 4.224 ID	5-inch 5.221 ID	6-inch 6.217 ID	8-inch 8.095 ID	10-inch 10.088 ID	12-inch 11.966 ID	Q Gallons per min
15	.01						15
20	.02						20
25	.03	.01					25
30	.04	.02					30
35	.06	.02	.01				35
40	.08	.03	.01				40
45	.10	.03	.01				45
50	.12	.04	.02				50
55	.14	.05	.02				55
60	.17	.06	.03				60
65	.19	.07	.03	.01			65
70	.23	.08	.03	.01			70
75	.26	.09	.03	.01			75
80	.29	.10	.04	.01			80
85	.33	.12	.04	.01			85
90	.36	.13	.05	.01			90
95	.40	.14	.06	.02			95
100	.44	.16	.06	.02			100
110	.53	.18	.08	.02			110
120	.62	.22	.08	.03	.01		120
130	.71	.25	.10	.03	.01		130
140	.82	.29	.12	.03	.01		140
150	.93	.34	.13	.04	.01		150
160	1.06	.37	.16	.04	.01		160
170	1.18	.41	.18	.05	.02		170
180	1.32	.46	.20	.06	.02	.01	180
190	1.45	.51	.22	.06	.02	.01	190
200	1.60	.56	.24	.07	.02	.01	200
220	1.92	.68	.29	.08	.03	.01	220
240	2.24	.80	.34	.08	.03	.01	240
260	2.60	.92	.39	.10	.03	.02	260
280	2.99	1.06	.45	.12	.04	.02	280
300	3.39	1.20	.51	.14	.04	.02	300
320	3.83	1.36	.58	.16	.05	.03	320
340	4.28	1.53	.65	.18	.06	.03	340
360	4.76	1.70	.72	.20	.07	.03	360
380	5.26	1.86	.80	.22	.08	.03	380
400	5.80	2.06	.87	.24	.08	.03	400
420	6.34	2.26	.96	.26	.08	.04	420
440	6.91	2.45	1.05				
460	7.51	2.67	1.13				
480	8.12	2.89	1.23				
500	8.75	3.11	1.33				
550	10.45	3.71	1.59				
600	12.27	4.38	1.86				

Table C-26

FRICTION HEAD LOSS IN PLASTIC IRRIGATION PIPELINES
MANUFACTURED OF PVC OR ABS COMPOUNDS
STANDARD DIMENSION RATIO - SDR = 32.5

For IPS Pipe

Q Gallons per min.	4-inch 4.224 ID	5-inch 5.221 ID	6-inch 6.217 ID	8-inch 8.095 ID	10-inch 10.088 ID	12-inch 11.966 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet						
600	12.27	4.38	1.86	.51	.18	.08	600
650	14.23	5.07	2.17	.60	.20	.08	650
700	16.34	5.81	2.49	.68	.24	.10	700
750	18.55	6.61	2.82	.78	.27	.12	750
800		7.46	3.18	.87	.30	.13	800
850		8.34	3.56	.98	.34	.14	850
900		9.28	3.96	1.09	.37	.16	900
950		10.23	4.38	1.21	.41	.18	950
1000		11.26	4.83	1.33	.45	.19	1000
1050		12.32	5.27	1.45	.50	.22	1050
1100		13.44	5.74	1.58	.55	.24	1100
1150		14.61	6.22	1.72	.59	.25	1150
1200		15.79	6.74	1.86	.64	.28	1200
1250		17.03	7.27	2.01	.69	.29	1250
1300		18.20	7.83	2.16	.74	.31	1300
1350			8.39	2.32	.80	.34	1350
1400			8.95	2.48	.85	.36	1400
1450			9.58	2.65	.91	.39	1450
1500			10.19	2.81	.97	.42	1500
1600			11.49	3.18	1.09	.47	1600
1700			12.84	3.55	1.22	.52	1700
1800			14.27	3.95	1.39	.59	1800

TABLE C-27

GUN SPRINKLER PERFORMANCE TABLES (Courtesy Nelson Corp.)

MODELS F100T, P100T & PC100T

24° Trajectory** Taper Bore Nozzle

PSI	Nozzle *.5" GPM	DIA	Nozzle .55 GPM	DIA	Nozzle .6 GPM	DIA	Nozzle .65" GPM	DIA	Nozzle .7 GPM	DIA	Nozzle .75" GPM	DIA	Nozzle .8" GPM	DIA	Nozzle .85 GPM	DIA	Nozzle .9 GPM	DIA	Nozzle 1.0 GPM	DIA
40	47	191	57	202	66	213	78	222	91	230	103	240	118	250	134	256	152	262		
50	50	205'	64	215	74	225	87	235	100	245	115	256	130	265	150	273	165	280	204	200
60	55	215	69	227	81	240	96	250'	110	260	126	270	143	280	164	288	182	295	224	316
70	60	225'	75	238	88	250	103	263	120	275	136	283	155	295	177	302	197	310	243	338
80	64	235'	79	248	94	260	110	273'	128	285'	146	295'	165	305	189	314	210	325	258	354
90	68	245'	83	258'	100	270'	117	283'	135	295'	155	306	175	315	201	326	223	335	274	362
100	72	255	87	268	106	280'	123	293	143	305	163	316	185	325	212	336	235	345	289	372
110	76	265	92	278	111	290'	129	303'	150	315'	171	324'	195	335	222	344	247	355	304	380

**The diameter of throw is approximately 3% less for the 21° trajectory angle, 6% less for 18°

*Note .5" and .55" taper nozzle available only with PC100 and F100

MODELS F100R, P100R & PC100R

24° Trajectory** Ring Nozzle

PSI	Ring .712 GPM	DIA	Ring .768 GPM	DIA	Ring .812 GPM	DIA	Ring .857 GPM	DIA	Ring .895 GPM	DIA	Ring .927 GPM	DIA	Ring .965 GPM	DIA
50	74	220	88	225	100	230'	115	240	129	250	150	255	167	260
60	81	235'	96	240	110	245	125	260'	141	270	164	275	183	280
70	88	245'	104	250	118	260	135	275	152	290	177	295'	198	300
80	94	255'	111	265	127	275	145	285	163	300	189	305	211	315
90	99	265'	117	275	134	285'	154	295	173	310'	201	315	224	325
100	105	270'	124	280	142	295'	162	305	182	320	212	325	236	335
110	110	275'	130	290	149	305	170	315	191	325'	222	335	248	345

**The diameter of throw is approximately 3% less for the 21° trajectory angle, 6% less for 18°

MODELS F150T & P150T

24° Trajectory** Taper Bore Nozzle

PSI	Nozzle .7 GPM	DIA	Nozzle .8 GPM	DIA	Nozzle .9 GPM	DIA	Nozzle 1.0 GPM	DIA	Nozzle 1.1 GPM	DIA	Nozzle 1.2 GPM	DIA	Nozzle 1.3 GPM	DIA
50	100	250	130	270'	165	290'	205	310'	255	330'	300	345'	350	360
60	110	265	143	285	182	305'	225	325	275	345'	330	365	385	380
70	120	280	155	300'	197	320	245	340'	295	360	355	380	415	395
80	128	290	165	310	210	335'	260	355	315	375'	380	395'	445	410
90	135	300	175	320'	223	345	275	365	335	390	405	410	475	425
100	143	310	185	330'	235	355'	290	375'	355	400'	425	420	500	440
110	150	320	195	340'	247	365'	305	385'	370	410'	445	430	525	450
120	157	330	204	350'	258	375'	320	395'	385	420	465	440	545	460

MODELS F150R & P150R

PSI	Ring .86 GPM	DIA	Ring .97 GPM	DIA	Ring 1.08 GPM	DIA	Ring 1.18 GPM	DIA	Ring 1.26 GPM	DIA	Ring 1.34 GPM	DIA	Ring 1.41 GPM	DIA
50	100	245	130	265	165	285	205	300	255	320	300	335'	350	350
60	110	260	143	280	182	300'	225	315	275	335	330	350	385	365
70	120	270	155	290'	197	310	245	330	295	350'	355	365	415	380
80	128	280'	165	300	210	320'	260	340'	315	360	380	380'	445	395'
90	135	290	175	310'	223	330	275	350	335	370'	405	390	475	405
100	143	300'	185	320	235	340'	290	360	355	380	425	400'	500	415
110	150	310	195	330	247	350	305	370	370	390	445	410	525	425
120	157	315	204	335	258	360	320	380'	385	400'	465	420'	545	435

**The diameter of throw is approximately 3% less for the 21° trajectory angle.

MODELS F200T & P200T

27° Trajectory** Taper Bore Nozzle

PSI	Nozzle 1.05 GPM	DIA	Nozzle 1.1 GPM	DIA	Nozzle 1.2 GPM	DIA	Nozzle 1.3 GPM	DIA	Nozzle 1.4 GPM	DIA	Nozzle 1.5 GPM	DIA	Nozzle 1.6 GPM	DIA	Nozzle 1.75 GPM	DIA	Nozzle 1.9 GPM	DIA
60	250	345	285	355	330	375	385	390'	445	410'	515	430	585	445	695	470	825	495
70	270	360	310	380	355	395'	415	410'	480	430	555	450'	630	465'	755	495	890	515
80	290	375	330	395	380	410'	445	430'	515	450	590	470	675	485	805	515	950	535
90	310	390'	350	410	405	425'	475	445'	545	465'	625	485'	715	505	855	535	1005	555
100	325	400	370	420'	425	440'	500	460'	575	480	660	500'	755	520	900	550	1060	575
110	340	410'	390	430	445	450	525	470'	605	495'	695	515'	790	535'	945	565	1110	590
120	355	420	405	440	465	460'	545	480'	630	505'	725	530	825	550	985	580	1160	605
130	370	425	425	445	485	465'	565	485	655	515'	755	540	860	560	1025	590	1210	620

**The diameter of throw is approximately 2% less for the 24° trajectory angle and 5% less for the 21° trajectory angle.

MODELS F200R & P200R

27° Trajectory** Ring Nozzle

PSI	1¼ Ring (1.29 actual) GPM	DIA	1⅜ Ring (1.46 actual) GPM	DIA	1½ Ring (1.56 actual) GPM	DIA	1⅝ Ring (1.66 actual) GPM	DIA	1¾ Ring (1.74 actual) GPM	DIA	1⅞ Ring (1.83 actual) GPM	DIA	2 Ring (1.93 actual) GPM	DIA
50	230	325	300	355	350	370	410	390	470	405	535	420	640	435
60	250	340	330	370	385	390	445	410	515	425	585	440	695	455
70	270	355	355	385	415	405	480	425	555	440	630	455	755	475
80	290	370	380	400	445	420	515	440	590	455	675	470	805	490
90	310	380	405	415	475	435	545	455	625	470	715	485	855	505
100	325	390	425	425	500	445	575	465	660	480	755	500	900	[illegible]
110	340	400	445	435	525	455	605	475	695	490	790	510	945	[illegible]
120	355	410	465	445	545	465	630	485	725	500	825	520	985	[illegible]
130	370	415	485	450	565	470	655	490	755	505	860	525	1025	[illegible]

**The diameter of throw is approximately 2% less for the 24° trajectory angle and 5% less for the 21° trajectory angle

APPENDIX D - GLOSSARY

Available Water Holding Capacity (AWC)

Available water holding capacity is the amount of water the soil will hold between field capacity and the permanent wilting point.

Carryover Soil Moisture

Moisture stored in soils within root zone depths during the winter, at times when the crop is dormant, or before the crop is planted. This moisture is available to help meet the consumptive water needs of the crop.

Consumptive Use

Consumptive use, often called evapo-transpiration, is the amount of water used by the vegetation in transpiration and building of plant tissue and that evaporated from adjacent soil or intercepted precipitation from plant foliage. If the unit of time is small, consumptive use is usually expressed as acre inches per acre or depth in inches, whereas, if the unit of time is large, such as a growing season or a 12-month period, it is usually expressed as acre feet per acre or depth in feet.

Consumptive Water Requirement

The amount of water potentially required to meet the evapo-transpiration needs of vegetative areas so that plant production is not limited from lack of water.

Crop Growth Stage Coefficient

A factor that modifies the Blaney-Criddle Formula which reflects the type of plant and stage of growth on consumptive use.

Discharge Head (Dynamic)

The elevation (in feet) between the center line of the pump, if a horizontal type, or the center line of discharge of a vertical turbine type, and the point of free discharge, plus the friction head between these two points, plus the residual pressure existing at the point of discharge (expressed in feet), plus the velocity head.

Drawdown

The difference, in feet, between the pumping level and the static level of the source.

Dynamic Head

The head condition that exists when water is flowing through a system of pipes, etc.

Effective Rainfall

Precipitation falling during the growing period of the crop that is available to meet the consumptive water requirements of crops. It does not include such precipitation as is lost to deep percolation below the root zone nor to surface runoff.

Field Capacity

The moisture percentage, on a dry weight basis, of a soil after rapid drainage has taken place following an application of water, provided there is no water table within capillary reach of the root zone. This moisture percentage usually is reached within two to four days after an irrigation, the time interval depending on the physical characteristics of the soil and the effect of the growing crop.

Friction Head

Pressure loss (in feet) due to frictional resistance when water flows through pipe, fittings, orifices, etc.

Gross Irrigation Requirement (Gross water application)

The net irrigation water requirement divided by the irrigation efficiency.

Head (H)

A term related to pressure but usually expressed in "feet" rather than "psi." It is derived from the fact that a column of fluid exerts pressure at a given point in relation to the height of the column above that point, and the density (weight per unit volume) of the fluid. For example, a column of water one foot high exerts a pressure of approximately 0.433 psi on its base. Thus, 1 ft. head (water) = 0.433 psi. or 2.31 ft. head = 1 psi.

Irrigation Depth

Is the soil depth used to determine irrigation water requirements for design of systems. A high moisture level must be maintained in this depth for top production of crops. It is not necessarily the maximum root depth for any given plant.

Irrigation Efficiency

The percentage of applied irrigation water that is stored in the soil and available for consumptive use by the crop. When the water is measured at the farm headgate, it is called farm-irrigation efficiency; when measured at the field, it is designated as field-irrigation efficiency; and when measured at the point of diversion, it may be called project-efficiency.

Irrigation Frequency

Refers to the allowable numbers of days between irrigations. It depends on the consumptive-use rate of a crop and on the amount of available moisture in the root zone (moisture extraction depth) between field capacity and the starting moisture level for irrigation. Irrigation period refers to the number of days a system, of given capacity, takes to irrigate the design area. Irrigation period should always be equal to, or less than, irrigation frequency.

Maximum Application Rate

Is the maximum rate that water can be applied to a soil during the time required for the soil to absorb the depth of application without runoff for the conditions of soil, slope and cover.

Net Irrigation Requirement (Net water application)

The depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, that is required consumptively for crop production and required for other related uses. Such related uses may include water required for leaching, frost protection, etc.

Peak Period Consumptive Use

Peak period consumptive use is the average daily rate of use of a crop occurring during a period between normal irrigations when such rate of use is at a maximum.

Static Head

The difference in elevation (in feet) between the source of supply and the point of free discharge, when there is no flow (sometimes called elevation head).

Suction Head

Velocity Head

The energy contained in a stream of water by reason of its velocity. It represents the force necessary to accelerate the water in the pipeline and is equivalent to the distance in feet through which it would have to fall in a vacuum to attain that velocity. This is a relatively small factor and need not be considered in the design of the average irrigation system.

Wilting Point

The wilting point is the moisture percentage, on a dry weight basis, at which plants can no longer obtain sufficient moisture to satisfy moisture requirements and will wilt permanently unless moisture is added to the soil profile.

APPENDIX E

CHEMICAL TREATMENT TO INHIBIT CLOGGING OF LOW PRESSURE IRRIGATION SYSTEMS

When using low-pressure irrigation systems, particularly if water supply contains iron, sulfides, or high pH, there is a chance of emitters becoming clogged. Sodium hypochlorite (liquid bleach) may be used to inhibit iron and slime clogging.

The key given in this appendix may be used to determine the amount of liquid bleach or any equipment adjustment needed. The key was developed by Harry W. Ford, horticulturist, Agricultural Research and Education Center, Lake Alfred, Florida.

Before using the key or recommending the chemical, it is necessary that good water quality data be obtained. Also, once treatment has been started, free residual chlorine must be measured. People unfamiliar with water test kits may want to contact the state wildlife and fish biologist or SCS biologist for assistance.

The rate at which liquid bleach (5.25 percent sodium hypochlorite - 50,000 ppm available chlorine) is injected into systems may be converted from ppm to ounces/min. by use of the following formula:

Chlorine Injection Rate (oz./min.) = K x Initial Rate (PPM) x Pumping Rate (GPM)

where the term K is a conversion constant =

$$\frac{128 \text{ oz./gal.}}{1{,}000{,}000 \times 0.05} = 0.00256$$

<u>EXAMPLE</u>: Drip system has a flow rate of 45 gallons per minute and the initial injection rate of 2 ppm of chlorine is desired. At what rate should the liquid bleach be injected into the drip system?

Chlorine Injection Rate = .00256 x <u>2</u> PPM x <u>45</u> GPM =

Conversion Factor: 1 ounce = 29.57 milliliters

A Key for Determining the Use of Sodium Hypochlorite (Liquid Chlorine) to Inhibit Iron and Slime Clogging of Low Pressure Irrigation Systems in Florida

Harry W. Ford
Professor (Horticulturist)
Agricultural Research and Education Center
Lake Alfred, Florida 33850

Terminology

D.P.D. type chlorine test kit. A required purchase to measure free residual chlorine. DO NOT use an orthotolodene swimming pool test kit which measures only total chlorine.

Free residual chlorine. The excess chlorine available to kill bacteria. Excess chlorine cannot be present until chemical reactions with chlorine have been satisfied.

Injection system. A good quality variable rate injection pump is suggested. Increase the rate of injection until the correct chlorine free residual is obtained.

Injection time. A 40 minute minimum injection of NaOCl should occur early enough in the irrigation cycle to permit 30 minutes of chlorine to reach the last emitter.

NaOCl. SEE: Sodium hypochlorite

Sodium hypochlorite (NaOCl). Liquid bleach or swimming pool chlorine either as 5.25% or 10%.

Water quality measurements are essential in order to use this key. Throughout the irrigation season, changes in water quality will occur for iron, sulfides, and pH. These should be checked at intervals and appropriate modifications made in the chlorine injection procedure.

Water holding tanks with air spaces should not be used on low pressure systems. They serve as chambers for bacterial slime growth particularly sulfur slime. The frequency of chlorination must be increased. Certain precipitation reactions associated with holding tanks have not been controlled in the range of pH 6.5-7.5.

A key for the use of sodium hypochlorite to inhibit slime clogging of low pressure irrigat[illegible] systems.

1. Surface water — go to 2
1. Well water — to to 10

2. 0.2 to 2.0 ppm maximum of iron; lower than pH 6.5 — go to 3
2. 0.2 to 2.0 ppm maximum of iron; higher than pH 6.5 — go to 8
2. 0 to 0.1 ppm Fe; lower than pH 7.0 — go to 3
2. 0 to 0.1 ppm Fe; higher than pH 7.0 — go to 8

3. Visible greenish algal clumps in water — go to 4
3. Water visibly free of biological growths — go to 6

4. Chlorine injected on vacuum intake line before filter — go to 5
4. Chlorine injected on pressure side after filter--filter will clog from slimes. Unsatisfactory procedure. Otherwise — go to 5

5. Sand filtration — go to A
5. Screen filtration--may have frequent backflush problems. Otherwise — go to A
5. Slotted filtration--will not remove algae--use only for larger than 7.0 gph spray jet nozzles. Keep daylight out of the white PVC filter. Otherwise — go to A

6. Inject NaOCl (sodium hypochlorite) on intake side of filter — go to 7
6. Inject NaOCl on pressure side after filter--unsatisfactory; otherwise — go to

7. Sand filter: more frequent backflushing during algal blooms. — go to B
7. Screen filter; backflush problems during algal blooms. Otherwise — go to A
7. Slotted filter; will not trap algal blooms. Use only with larger than 7.0 gph micro sprinklers. Keep out light. Otherwise — go to B

8. Trickle long path emitters--use only sand filtration. Sludge precipitate may occur after 800 hrs even with NaOCl. Otherwise — go to A
8. Micro sprinkler system; 7 gph or greater each emitter: May or may not accumulate sufficient sludge for blockage: Use sand filtration. Otherwise — go to A
8. Micro sprinkler system; emitters less than 7 gph. May have sludge blockage. — go to A

10. Well water contains iron but no sulfides — go to 11
10. Well water with no iron and also no sulfides — go to 19
10. Well water with no iron but contains sulfides — go to 21
10. Well water containing iron and also sulfides — go to 25

11. pH less than 6.5 — go to
11. pH 6.5 to 7.5 — go to
11. pH 7.5 to 8.0 — go [illegible]
11. pH higher than 8.0 Unsatisfactory for low pressure irrigation.

12. Open well with drop type suction inlet. Foot valve. Centrifugal pump. NaOCl injection point deep into well.

12. Submergeable pump. Covered top. Injection point for NaOCl as deep into well as possible.

Turbine pump. NaOCl injected below turbine | go to 13
Turbine pump. NaOCl injected just after pump on pressure side. | go to 15

13. Water contains less than 3.5 ppm iron | go to 14
13. Water contains more than 3.5 ppm iron. Unsatisfactory

No pressure holding tank on line | go to C
Pressure holding tank with air chamber. Unsatisfactory

15. If well is contaminated with iron deposits and iron concentration is less than 2 ppm | go to C
15. If iron is more than 2 ppm. Unsatisfactory

Water almost free of suspended solids and/or organic-iron complexing agents. | go to 17
Water contains suspended solids and organic-iron complexing agents. Less than 1 ppm iron. May clog from suspended sludge particularly if iron is more than 1 ppm. Otherwise | go to D

17. Open well with centrifugal pump. Submerged pumps with deep injection for NaOCl. Iron less than 2 ppm. More than 2 ppm is Unsatisfactory | go to B
17. Turbine pump. Surface injection for NaOCl. No holding tank. Iron less than 1.0 ppm. More than 1 ppm is Unsatisfactory | go to D
17. Turbine pump. Deep injection for NaOCl. No holding tank. Iron less than 2 ppm. More than 2 ppm is Unsatisfactory | go to D

Open well with centrifugal pumps and submerged pumps with deep NaOCl injection. Iron less than 2 ppm. Note: System will clog in 24 hours if chlorination stops. Otherwise | go to E

Turbine pump. As deep NaOCl injection as possible. Iron less than 2 ppm. System will clog in 24 hours if chlorination stops. Otherwise | go to E

19. Water almost free of suspended solids and/or organic discoloration | go to 20
19. Water contains suspended solids and/or discoloration | go to F

Open wells and/or other means of well contamination | go to F
No well contamination. MAY NOT NEED CHLORINATION. Otherwise | go to G

21. Sulfides less than 4 ppm | go to 22
21. Sulfides more than 4 ppm may be toxic to plant roots

2. Artesian well | go to 23
2. Well is not artesian | go to 24

23. No leaks in well casing or other points on vacuum side. Check valve. Positive artesian pressure during irrigation season. | go to G
23. Any one of the following: Possible leaks in well casing or other points on vacuum side. Old gate valve on uum side. Pressure holding tank near pump. Artesian ure may be negative during dry season. | go to H

on vacuum side of pump | go to I
of pump. Pressure holding Artesian pressure negative | go to J

1 to 3.0 ppm | go to 26
than 0.6 ppm | go to 26
than 0.6 ppm. Unsatisfactory
osprinklers. Otherwise | go to 26

26. No air leaks in system. go to _H_

26. Air leaks on vacuum side of pump or there is a holding tank near the pump. go to _J_

Chlorine Treatment

A. Less than pH 7.0: Use minimum of 1 ppm (Mg/L) free residual chlorine as measured at the last emitter (Start with 3 ppm free residual as measured near the pump at the first emitter). Inject for 40 min (minimum) each 6 hours of accumulative irrigation time.

A. pH 7.0-7.5: Use minimum 1.5 ppm (Mg/L) free residual chlorine as measured at the last emitter. (Start with 3.5 ppm free residual as measured near the pump at the first emitter). Injected for 40 min (Minimum) each 6 hours of accumulated irrigation time.

A. pH 7.5-8.0: Use minimum 2.0 ppm (Mg/L) free residual chlorine as measured at the last emitter. (Start with 4.0 ppm free residual as measured near the pump at the first emitter). Inject for 40 min. (minimum) each 6 hours accumulated irrigation time.

B. pH 7.0: Use minimum of 1 ppm (Mg/L) free residual chlorine as measured at the last emitter (Start with 3 ppm free residual as measured near the pump at the first emitter). Inject for 40 min (minimum) each 12 hours of accumulative irrigation time.

B. pH 7-7.5: Use minimum 1.5 ppm (Mg/L) free residual chlorine as measured at the last emitter. (Start with 3.5 ppm free residual as measured near the pump at the first emitter). Injected for 40 min (Minimum) each 12 hours of accumulated irrigation time.

B. pH 7.5-8: Use minimum 2.0 ppm (Mg/L) free residual chlorine as measured at the last emitter. (Start with 4.0 ppm free residual as measured near the pump at the first emitter). Inject for 40 min. (minimum) each 12 hours accumulated irrigation time.

C. pH less than 6.3: Use minimum of 1 ppm (Mg/L) free residual chlorine as measured at the last emitter (Start with 3 ppm free residual as measured near the pump at the first emitter). Inject for 40 min (minimum) each 6 hours of accumulative irrigation time.

D. pH 6.3-7.5. Use minimum 1 ppm (Mg/L) free residual chlorine as measured at last emitter (Start with 3 ppm free residual as measured near the pump at the first emitter). Inject NaOCl for minimum of 40 minutes each 2 hours of accumulated irrigation time.

E. pH 7.0-7.5. Use minimum of 2 ppm (Mg/L) free residual chlorine as measured at the last emitter. (Start with 4 ppm free residual as measured near the pump at the first emitter). Inject NaOCl CONTINUOUSLY.

F. Select the treatment and pH range of the water as indicated.

pH 7.0: Use minimum of 1 ppm (Mg/L) free residual chlorine as measured at the last emitter (Start with 3 ppm free residual as measured near the pump at the first emitter). Inject for 40 min (minimum) each 12 hours of accumulative irrigation time.

pH 7-7.5: Use minimum 1.5 ppm (Mg/L) free residual chlorine as measured at the last emitter. (Start with 3.5 ppm free residual as measured near the pump at the first emitter). Injected for 40 min (Minimum) each 12 hours of accumulated irrigation time.

pH 7.5-8: Use minimum 2.0 ppm (Mg/L) free residual chlorine as measured at the last emitter. (Start with 4.0 ppm free residual as measured near the pump at the first emitter). Inject for 40 min. (minimum) each 12 hours accumulated irrigation time.

7.5 use NaOCl with minimum of 0.75 ppm (Mg/L) free residual chlorine as
ed at the end of line (2.5 ppm free residual near pump).
for a minimum of 40 minutes each 25 to 40 hours accumulative time.
carefully for any sulfur slime formation in the area of the last emitter
system.

-8.0 increase treatment by 1 ppm of NaOCl.

7.5 use NaOCl with minimum of 0.75 ppm (Mg/L) free residual chlorine
sured at end of line (2.5 ppm free residual near pump).
for a minimum of 40 minutes each 10 hours of accumulative time.
carefully for any sulfur slime formation in the area of the last emitter
system.

-8.0 increase treatment by 1 ppm of NaOCl.

7.5 use NaOCl with minimum of 0.75 ppm (Mg/L) free residual chlorine
isured at end of line (2.5 ppm free residual near pump).
: for a minimum of 40 minutes each 10-20 hours accumulative time.
carefully for any sulfur slime formation in the area of the last emitter
e system.

5-8.0 increase treatment by 1 ppm of NaOCl.

o 7.5 use NaOCl with minimum of 0.75 ppm (Mg/L) free residual chlorine
asured at end of line (2.5 ppm free residual near pump).
t for a minimum of 40 minutes each 6-8 hours accumulative time.
carefully for any sulfur slime formation in the area of the last emitter
e system.

5-8.0 increase treatment by 1 ppm of NaOCl.

APPENDIX F - TECHNICAL RELEASE 21

INPUT DATA FOR TABLE 4-2

80/80 ECHO LIST OF TR21 INPUT DATA

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
JOB I                                                                          1
TITLE=    SOUTH CAROLINA CLIMATIC ZONE 1      6-20-84                          2
          N.W. & W.CENTRAL DIV. WEATHER DATA AVERAGES -1951-1980 NORMS         3
SITE-SPECS      34         30      49.74       80          1.         8         4
TEMP           42.6       45.0      52.3      61.7       69.3      75.9        5
TEMP           79.0       78.4      72.8      61.8       52.2      44.5        6
PRECIP         4.68       4.24      5.74      4.07       4.12      4.19        7
PRECIP         4.53       4.05      4.20       3.0       3.01      3.95        8
CROP      CORN, GRAIN            1.04010720 0.75 0.75 0.75 0.75                9
CROP      CORN, SILAGE          11.04010720 0.75 0.75 0.75 0.75               10
CROP      CORN, SWEET            5.04010630 0.75 0.75 0.75 0.75               11
CROP      SOYBEANS              20.05100930 0.65 0.65 0.75 0.75               12
CROP      SOYBEANS, LATE        20.06101028 0.65 0.65 0.75 0.75              12A
CROP      SMALL VEGETABLES      22.02200421 0.60 0.60 0.75 0.75               13
CROP      SMALL VEGETABLES      22.03200519 0.60 0.60 0.75 0.75               14
CROP      SMALL VEGETABLES      22.04200619 0.60 0.60 0.75 0.75               15
CROP      SMALL VEGETABLES      22.04200719 0.60 0.60 0.75 0.75               16
CROP      SMALL VEGETABLES      22.08011015 0.60 0.60 0.75 0.75               17
CROP      TOMATOES              21.05010829 0.65 0.65 0.75 0.75               18
CROP      SORGHUM               19.06010930 0.70 0.70 0.75 0.75               19
CROP      PEANUTS               26.05010918 0.55 0.55 0.75 0.75               20
CROP      WINTER WHEAT, FALL    24.11011207 0.70 0.70 0.75 0.75               21
CROP      WINTER WHEAT, SPRING  25.02150531 0.70 0.70 0.75 0.75              21a
CROP      SNAP BEANS             3.04200619 0.60 0.60 0.75 0.75               22
CROP      GRAPES                14.04010915 0.50 0.50 0.75 0.75               23
CROP      PASTURE GRASSES       17.03150915 0.75 0.75 0.75 0.75               24
CROP      ALFALFA                2.03150915 0.80 0.80 0.75 0.75               25
CROP      PECANS AND WALNUTS    23.04011010 0.60 0.60 0.75 0.75               26
CROP      EARLY PEACHES          4.03200615 0.60 0.60 0.75 0.75               27
CROP      MID S. PEACHES         4.03200715 0.60 0.60 0.75 0.75               28
CROP      LATE PEACHES           4.03200815 0.60 0.60 0.75 0.75               29
CROP      APPLES                 4.03200915 0.60 0.60 0.75 0.75               30
CROP      STRAWBERRIES          22.03200519 0.60 0.60 0.75 0.75               31
CROP      COTTON                12.04200920 0.60 0.60 0.75 0.75               32
END JOB                                                                       33
12345678901234567890123456789012345678901234567890123456789012345678901234567890
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END OF TR21 INPUT DATA

INPUT DATA FOR TABLE 4-2

80/80 ECHC LIST OF TR21 INPUT DATA

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JOB I
TITLE=    SOUTH CAROLINA CLIMATIC ZONE 2     7-3-84
          CENTRAL DIVISION WEATHER DATA (1951-80 NORMALS)
SITE-SPECS       34         00       47.31        80.         1.0          8
TEMP           45.0       47.4        54.9        63.9       71.4       77.3
TEMP           80.4       79.6        74.4        63.7       54.5       47.1
PRECIF         4.02       3.80        4.66        3.37       3.95       4.87
PRECIP         5.43       4.94        4.07        2.60       2.35       3.25
CROP      CORN, GRAIN              1.03200708 0.75 0.75 0.75 0.75
CROP      CORN, SILAGE            11.03200708 0.75 0.75 0.75 0.75
CROP      CORN, SWEET              5.03200618 0.75 0.75 0.75 0.75
CROP      SOYBEANS                20.05010920 0.65 0.65 0.75 0.75
CROP      SOYBEANS, LATE          20.06101028 0.65 0.65 0.75 0.75
CROP      SMALL VEGETABLES        22.02200421 0.60 0.60 0.75 0.75
CROP      SMALL VEGETABLES        22.03200519 0.60 0.60 0.75 0.75
CROP      SMALL VEGETABLES        22.04200619 0.60 0.60 0.75 0.75
CROP      SMALL VEGETABLES        22.04200719 0.60 0.60 0.75 0.75
CROP      SMALL VEGETABLES        22.08011015 0.60 0.60 0.75 0.75
CROP      TOMATOES                21.04200818 0.65 0.65 0.75 0.75
CROP      PEANUTS                 26.04200907 0.55 0.55 0.75 0.75
CROP      GRAPES                  14.03150831 0.50 0.50 0.75 0.75
CROP      WINTER WHEAT, FALL      24.11011231 0.70 0.70 0.75 0.75
CROP      WINTER WHEAT, SPRING    25.01010531 0.70 0.70 0.75 0.75
CROP      SNAP BEANS               3.04100609 0.60 0.60 0.75 0.75
CROP      SORGHUM                 19.05150915 0.70 0.70 0.75 0.75
CROP      PASTURE GRASSES         17.03150915 0.75 0.75 0.75 0.75
CROP      ALFALFA                  2.03010831 0.80 0.80 0.75 0.75
CROP      PECANS AND WALNUTS      23.03200930 0.60 0.60 0.75 0.75
CROP      EARLY PEACHES            4.03100605 0.60 0.60 0.75 0.75
CROP      MID SEASON PEACHES       4.03100705 0.60 0.60 0.75 0.75
CROP      LATE PEACHES             4.03100805 0.60 0.60 0.75 0.75
CROP      STRAWBERRIES            22.03100509 0.60 0.60 0.75 0.75
CROP      COTTON                  12.04200920 0.60 0.60 0.75 0.75
CROP      WATERMELONS             15.03250712 0.60 0.60 0.75 0.75
CROP      TOBACCO                 21.04100630 0.70 0.70 0.75 0.75
END JOB
12345678901234567890123456789012345678901234567890123456789012345678901234567890

END OF TR21 INPUT DATA
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80/80 ECHO LIST OF TR21 INPUT DATA

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JOB I                                                                          1
TITLE=    SOUTH CAROLINA CLIMATIC ZONE 3    7-3-84                             2
          N.E. AND SOUTHERN DIVISIONS WEATHER DATA AVG (1951-80 NORMS)         3
SITE-SPECS         33        10       48.78        80.        1.        8      4
TEMP             46.2      48.4        55.4       63.9      71.4      77.2     5
TEMP             80.2      79.6        74.9       64.7      55.5      48.2     6
PRECIP           3.62      3.65        4.41       2.68      4.13      5.21     7
PRECIP           6.08      5.75        4.68       2.87      2.33      3.20     8
CROP      CORN, GRAIN          1.03100629 0.75 0.75 0.75 0.75                  9
CROP      CORN, SILAGE        11.03100629 0.75 0.75 0.75 0.75                 10
CROP      SORGHUM             19.05150915 0.70 0.70 0.75 0.75                 11
CROP      SOYBEANS            20.05010920 0.65 0.65 0.75 0.75                 12
CROP      SOYBEANS, LATE      20.06101028 0.65 0.65 0.75 0.75                 13
CROP      SMALL VEGETABLES    22.09011115 0.60 0.60 0.75 0.75                 14
CROP      SMALL VEGETABLES    22.02150416 0.60 0.60 0.75 0.75                 15
CROP      SMALL VEGETABLES    22.02150516 0.60 0.60 0.75 0.75                 16
CROP      SMALL VEGETABLES    22.02150615 0.60 0.60 0.75 0.75                 17
CROP      SMALL VEGETABLES    22.03010430 0.60 0.60 0.75 0.75                 18
CROP      SMALL VEGETABLES    22.03010530 0.60 0.60 0.75 0.75                 19
CROP      SMALL VEGETABLES    22.03010629 0.60 0.60 0.75 0.75                 20
CROP      SMALL VEGETABLES    22.08011015 0.60 0.60 0.75 0.75                 21
CROP      TOMATOES            21.03010629 0.65 0.65 0.75 0.75                 22
CROP      TOMATOES            21.04200818 0.65 0.65 0.75 0.75                 23
CROP      CORN, SWEET          5.03100608 0.75 0.75 0.75 0.75                 24
CROP      PEANUTS             26.04200907 0.55 0.55 0.75 0.75                 25
CROP      GRAPES              14.03150831 0.50 0.50 0.75 0.75                 26
CROP      WINTER WHEAT, FALL  24.11011231 0.70 0.70 0.75 0.75                 27
CROP      WINTER WHEAT, SPRING 25.01010531 0.70 0.70 0.75 0.75                28
CROP      SNAP BEANS           3.04010531 0.60 0.60 0.75 0.75                 29
CROP      PASTURE GRASSES     17.05150915 0.75 0.75 0.75 0.75                 30
CROP      COTTON              12.04200920 0.60 0.60 0.75 0.75                 31
CROP      PECANS AND WALNUTS  23.03100930 0.60 0.60 0.75 0.75                 32
CROP      EARLY PEACHES        4.03010530 0.60 0.60 0.75 0.75                 33
CROP      MID-SEASON PEACHES   4.03010630 0.60 0.60 0.75 0.75                 34
CROP      STRAWBERRIES        22.03010430 0.60 0.60 0.75 0.75                 35
CROP      TOBACCO             21.04100630 0.70 0.70 0.75 0.75                 36
CROP      WATERMELONS         15.03250712 0.60 0.60 0.75 0.75                 37
END JOP                                                                       38
12345678901234567890123456789012345678901234567890123456789012345678901234567890

END OF TR21 INPUT DATA
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APPENDIX G - REFERENCES

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